# “Study of Electronic Vehicle Controls and Unintended Acceleration”

# NHTSA Informational Briefing

- June 30, 2010

NHTSA
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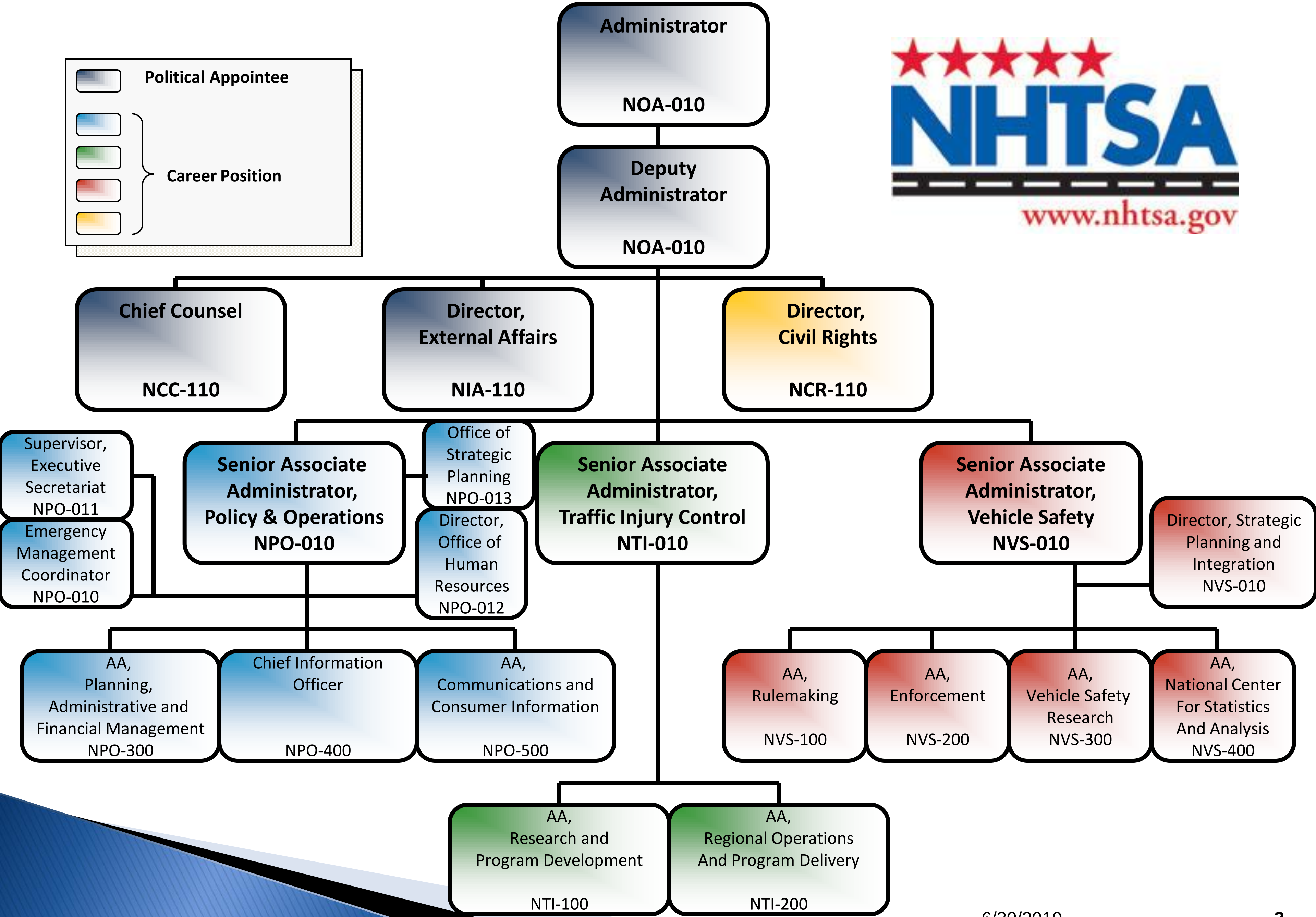
# Overview of NHTSA and its Activities Related to Unintended Acceleration and Vehicle Electronics

- Daniel C. Smith
  Associate Administrator
  Enforcement



▨ Political Appointee

🟦 🟩 🟥 🟨 Career Position

NHTSA

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**Administrator**
**NOA-010**

**Deputy Administrator**
**NOA-010**

**Chief Counsel**
**NCC-110**

**Director, External Affairs**
**NIA-110**

**Director, Civil Rights**
**NCR-110**

Supervisor, Executive Secretariat
NPO-011

Emergency Management Coordinator
NPO-010

**Senior Associate Administrator, Policy & Operations**
**NPO-010**

Office of Strategic Planning
NPO-013

Director, Office of Human Resources
NPO-012

AA, Planning, Administrative and Financial Management
NPO-300

Chief Information Officer
NPO-400

AA, Communications and Consumer Information
NPO-500

**Senior Associate Administrator, Traffic Injury Control**
**NTI-010**

AA, Research and Program Development
NTI-100

AA, Regional Operations And Program Delivery
NTI-200

**Senior Associate Administrator, Vehicle Safety**
**NVS-010**

Director, Strategic Planning and Integration
NVS-010

AA, Rulemaking
NVS-100

AA, Enforcement
NVS-200

AA, Vehicle Safety Research
NVS-300

AA, National Center For Statistics And Analysis
NVS-400

6/30/2010

# NHTSA Resources

- Budget (FY 2010)

| | |
|---|---|
| Total appropriation: | **$ 872,777,000** |
| Grant programs: | $ 601,000,000 |
| Behavioral programs: | $ 71,517,000 |
| National Driver Register: | $ 5,850,000 |
| Vehicle safety: | $ 75,310,000 |
| Administrative Expenses: | $ 119,100,000 |

- Personnel

| | |
|---|---|
| Overall staffing level: | **617 FTE** |
| Grants programs: | 82 FTE |
| Behavioral programs: | 70 FTE |
| National Driver Register | 11 FTE |
| Vehicle safety programs: | 283 FTE |
| Administrative: | 171 FTE |

# National Center for Statistics and Analysis

- Several important data bases, including:
    - **Fatality Analysis Reporting System (FARS):** complete census of highway fatalities
    - **Crashworthiness Data System (CDS):** nationally representative sample of police-reported crashes, focused on crashworthiness
    - **General Estimates System (GES):** sample of police-reported crashes
    - **Special Crash Investigations (SCI):** in-depth investigations of limited number of crashes

- Significant analytical capabilities support:
    - Public awareness campaigns
    - Rulemaking, research, and enforcement activities

# Vehicle Safety Research

- **Three Areas of Focus & Key Programs:**
  - Crashworthiness
    - Frontal and Side Impact, Dynamic Rollover, Child Protection, Alternative Energy Vehicles…
  - Crash Avoidance
    - Advanced Collision Avoidance, Intellidrive, Distraction, Alcohol…
  - Biomechanics
    - Human Injury Mechanisms, Crash Test Dummies, Injury Criteria…
- **Prioritized based on potential for fatality/injury reductions**
  - With consideration for special populations and risk scenarios
- **Primarily focused on regulatory outcomes**
  - But with some continuing component of exploratory & innovative “pure” research

# Rulemaking

- NHTSA issues Federal Motor Vehicle Safety Standards (FMVSS) covering many aspects of vehicle and equipment safety
- Standards must be practicable, meet the need for motor vehicle safety (i.e., protect against unreasonable risk of accidents, death or injury), and be stated in objective terms
- Rulemakings prompted by
  - Data indicating specific need to address an area of risk (e.g., frontal or side crashes)
  - Congressional mandate
  - Petition from public

# Rulemaking (cont'd)

- FMVSS generally contain performance standards; manufacturers must certify that they meet them
- Standards supported by research on need, options, countermeasures, test procedures
- Standards address specific areas of risk (e.g., rollover) and technologies likely to address the risk (e.g., ESC)
- But FMVSS have not looked at broad subject areas (e.g., electronics and software) that are common to various crashworthiness and crash avoidance technologies: is there a need to address these broad areas? Are federal standards the best method?

# Enforcement

- Compliance with FMVSS
  - NHTSA’s Office of Vehicle Safety Compliance selects vehicles and equipment for testing and inspection to determine compliance
  - Vehicles or equipment that do not comply must be recalled
- Defect investigations
  - Vehicles or equipment that contain defects related to safety (i.e., they present an unreasonable risk) must be recalled

# Defect Investigation Process

- NHTSA’s Office of Defects Investigation constantly screens information for evidence of possible defect trends in particular vehicles or equipment:
  - Complaints (VOQs) from consumers (over 38,000 complaints in 2009, and already that many in 2010)
  - Information from manufacturers (early warning data, technical bulletins, foreign recalls)

- NHTSA investigates where a defect trend appears to exist, focusing on specific make, model, and model years showing trend

- Where it can demonstrate a defect and that it is safety related, NHTSA insists on recall

# Defect Investigation Process (cont'd)

- NHTSA must be able to show a significant number of failures that are vehicle-based and that the failures create an unreasonable risk

- As with FMVSS development, defect investigations do not entail broad examinations of entire technological areas such as the electronic systems that support many vehicle functions

# Recalls

- More than 600 recalls of vehicles and equipment in an average year
- About 75 percent of recalls are related to defects; the remainder concern compliance
- Although only about 23 percent of recalls result from NHTSA investigations, those recalls account for 50 to 60 percent of products recalled

# Why NHTSA Sought Help from This Panel

- Agency has done several investigations of UA in Toyota and other vehicles, leading to many recalls of millions of vehicles (discussed later)

- However, despite several investigations of Toyota's ETC system, NHTSA has not been able to find a defect

- NHTSA retained NASA to help it identify any possible defects in Toyota ETC system that can realistically be expected to cause UA in real-world use; may lead to a defect investigation

- The ETC issue has brought to the fore two important and broader issues
  - Causes and possible remedies for UA generally, which is an issue affecting all vehicle manufacturers
  - The general need for greater attention to safety-critical electronics systems in vehicles

# Why NHTSA Sought Help from This Panel

- This year, Congress raised several questions about NHTSA's expertise in electronics and its resources to address possible electronic issues

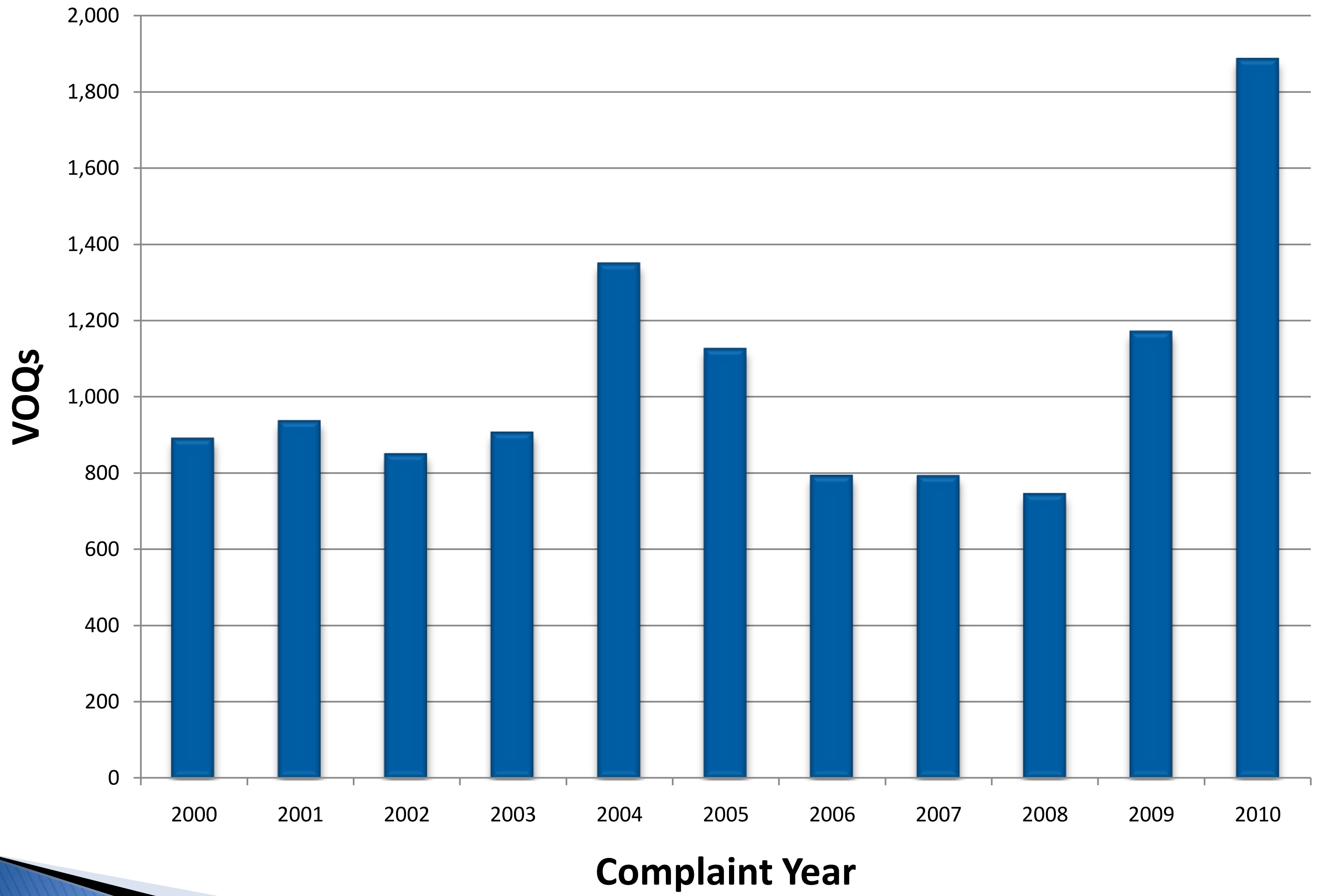
- Pending bills would
  - Require NHTSA to obtain and focus more resources on vehicle electronics
  - Require NHTSA to issue standards on UA-related subjects such as brake override, pedal placement, transmission position marking, push-button ignition, EDRs, and electronic control systems

# Why NHTSA Sought Help from This Panel

- UA continues to be an issue affecting all manufacturers (see following slides)

- Therefore, NHTSA enlisted aid of NAS to set up independent panel to:
  - Study causes of UA across the industry, and
  - Make recommendations to NHTSA about actions it should take to address safety of all electronic vehicle control systems

# Industry-Wide
# Alleged UA Complaints



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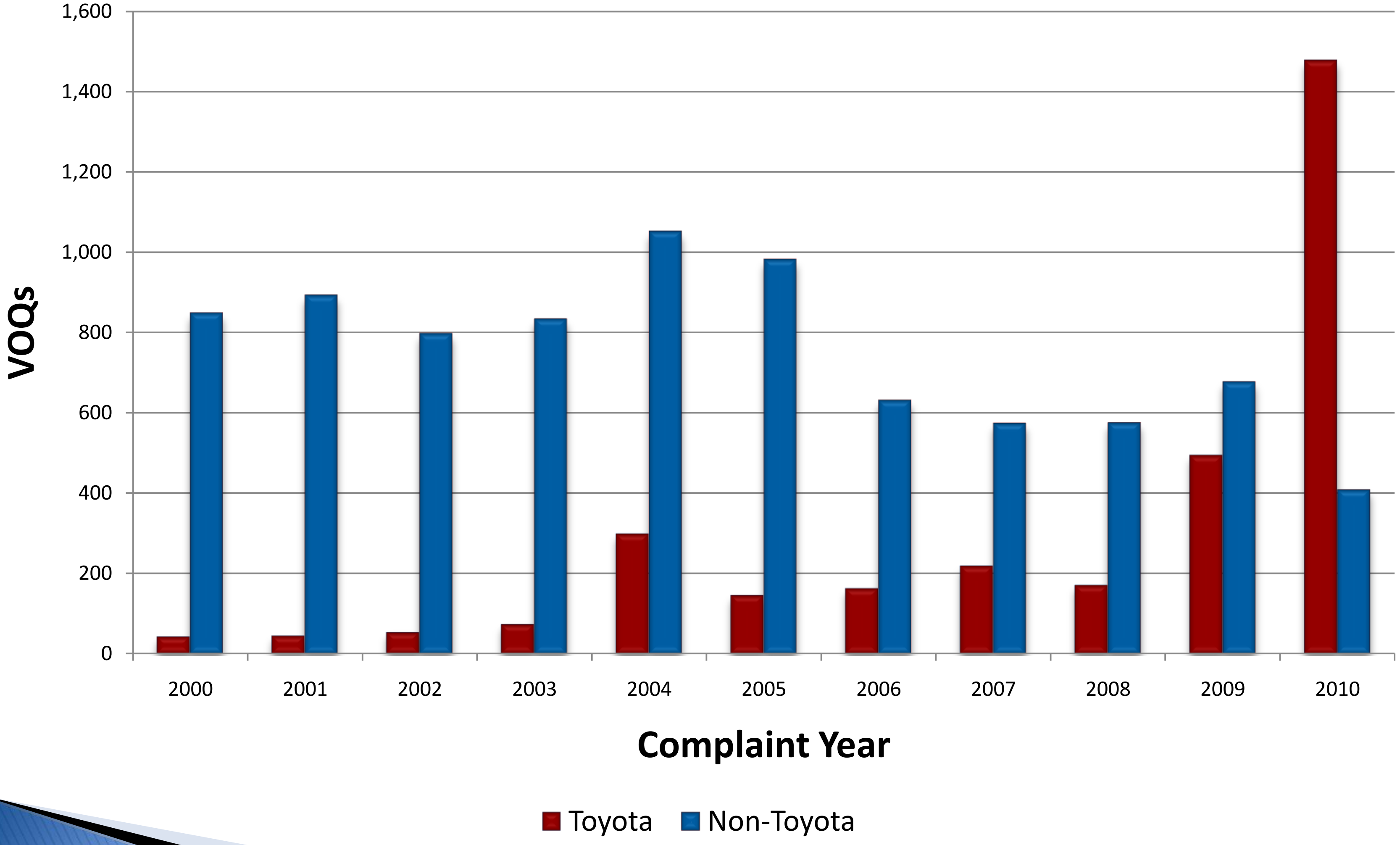
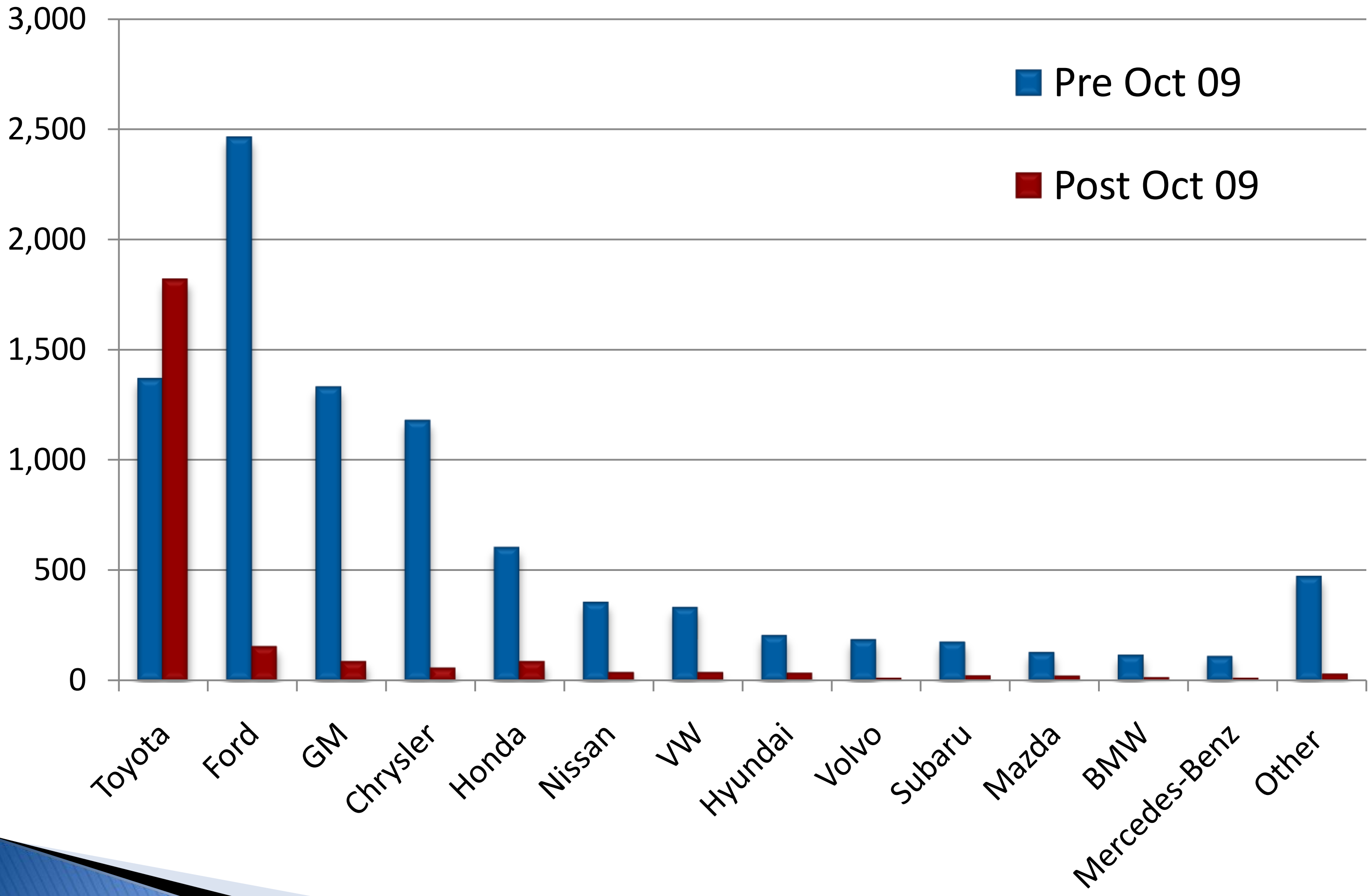
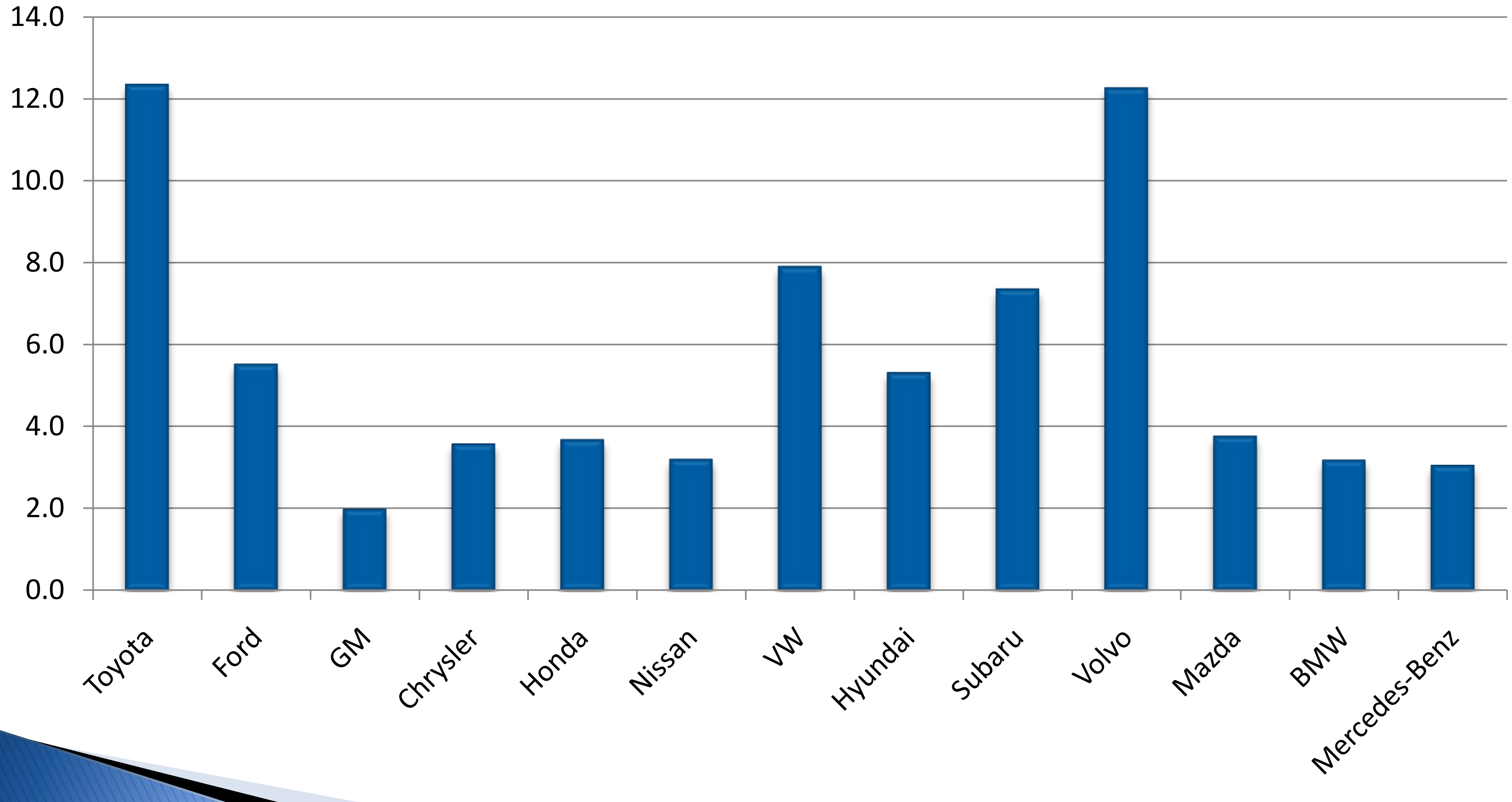


# UA VOQs
# After Manual Review



# Alleged UA Complaint Rate per 100K
# MY 1998-2010



# Today's Program

- **Known vehicle-based factors:** what investigations and recalls have occurred with regard to vehicle-based causes of UA
- **Human factors:** their role in UA and ongoing research on that subject
- **Other possible electronic causes:** what NHTSA, with NASA's help, is doing currently to determine if flaws in Toyota ETC systems may be responsible for some of the UA events in those vehicles
- **Standards:** current standards relevant to UA and standards under consideration
- **Research on electronics**: activities NHTSA currently has underway related to vehicle electronics and areas where further research may be needed
- **Recommendations:** areas where the agency desires specific recommendations on the subject of UA and vehicle control systems

# Known Vehicle Causes of Unintended Acceleration

- Richard Boyd
  Acting Director
  Office of Defects Investigation

# “Sudden Acceleration Incidents”

- Definition: “Unintended, unexpected, high-power accelerations from a stationary position or a very low initial speed accompanied by an apparent loss of braking effectiveness.” *NHTSA, “An Examination of Sudden Acceleration,” 1989 (Silver Book).*

- Characteristics:
  - Engine power: sudden, large increase in engine power, at or near wide-open throttle (WOT)
  - Brakes: allegedly ineffective (brake application often cited as initiator)
  - Initial speed: over 90% start from stationary position or low-speed
  - Location: most occur in parking lots, garages, driveways, car washes
  - Operating mode: initial shift from PARK to REVERSE or DRIVE
  - Crashes: most incidents result in crashes
  - Drivers: older drivers over-represented
  - Evidence: generally no problems with throttle control or brake systems identified in post-incident vehicle inspection or subsequent vehicle service

- Technical summary:
  - Evidence suggested that most SAI probably involve the driver unintentionally pressing the accelerator when braking was intended
  - No mechanism for temporary, self-correcting brake failure was found to exist

# “Unintended Acceleration”:  A Broader Concept

- The Silver Book’s definition of “Sudden Acceleration” did not include all types of incidents involving unwanted engine power

- More recently, “unintended acceleration” (UA) has been used as a catch-all term that is not limited to high engine power, low initiation speeds or allegations of brake ineffectiveness

- Included in UA are the rare incidents involving prolonged open throttle events

- However, data indicate that by far the most common incidents are still those involving sudden, high-power accelerations from a stationary position or very low initiation speed, as in parking lots and driveways, that also include allegations of brake ineffectiveness

# Known Vehicle Factors for UA

- Throttle control history:
  - Over 30 years of investigations & recalls (since 1970’s)

  - Wide variety of vehicle causes for unwanted engine power

  - In the last 25 years:
    - 109 defect investigations, influencing 34 recalls
    - 174 recalls involving 15.6 million products

- Vehicle Causes Identified in Investigations & Recalls:
  - Stuck Throttle
    - Conditions that prevent or inhibit throttle return to idle when the driver releases the accelerator
    - Most of these conditions do NOT involve full engine power
    - Examples: pedal entrapment, cable binding, throttle icing, cruise control servo

  - Self-Actuation
    - Conditions that cause the throttle to open or result in elevated idle speed
    - Most of these conditions do NOT involve sudden, full engine power
    - Examples: cruise control computer, engine control module, accelerator pedal sensor, high idle & engine surge conditions in heavy vehicles

  - No defect conditions have been identified that:
    - Resulted in sudden WOT; and
    - Simultaneous loss of brake effectiveness

# Investigations for UA

| | | | INFLUENCED RECALLS | |
|---|---|---|---|---|
| Subject | | INV. | NO. | UNITS RECALLED |
| Vehicle based cause | Stuck throttle | 57 | 29 | 9,428,000 |
| | Self-actuation | 11 | 1 | 5,000 |
| Vehicle features related to pedal misapplication | | 41 | 4 | 1,815,000 |
| Total | | 109 | 34 | 11,247,000 |

## Observations:

- Stuck throttle:
  - Most likely to result in an influenced recall (approx 50%)
  - 85% of influenced recalls
  - 84% of products recalled
- Vehicle features related to pedal misapplication:
  - Three recalls to install brake transmission shift interlocks (BTSI)
  - One recall to ensure adequate spacing of accelerator and brake pedals

# Recalls for UA

| | RECALLS | | | PRODUCTS RECALLED | | |
|---|---|---|---|---|---|---|
| **Category** | **MFR** | **ODI** | **Total** | **MFR** | **ODI** | **Total** |
| Stuck throttle | 118 | 29 | 147 | 4,043,000 | 9,428,000 | 13,471,000 |
| Self-actuation | 21 | 1 | 22 | 313,000 | 5,000 | 318,000 |
| Vehicle features related to pedal misapplication | 1 | 4 | 5 | 1,000 | 1,815,000 | 1,815,000 |
| Total | 140 | 34 | 174 | 4,356,000 | 11,247,000 | 15,604,000 |

Observations:

- Most recalls address defects in “stuck throttle” category
    - 84% of recalls
    - 86% of products recalled
- NHTSA influenced 20% of recalls and 72% of products recalled
- Three Toyota recalls in 2009 & 2010:
    - All involved stuck throttle conditions - pedal entrapment & sticking pedals (internal friction)
    - 7,584,000 vehicles; almost half (48%) of total since 1985

# Long-Duration, High-Speed Incidents

- Rare events – require multiple conditions
  - Defect condition must result in sustained high-power at or near WOT (e.g., floor mat entrapment, which occurs after pedal-to-floor acceleration)

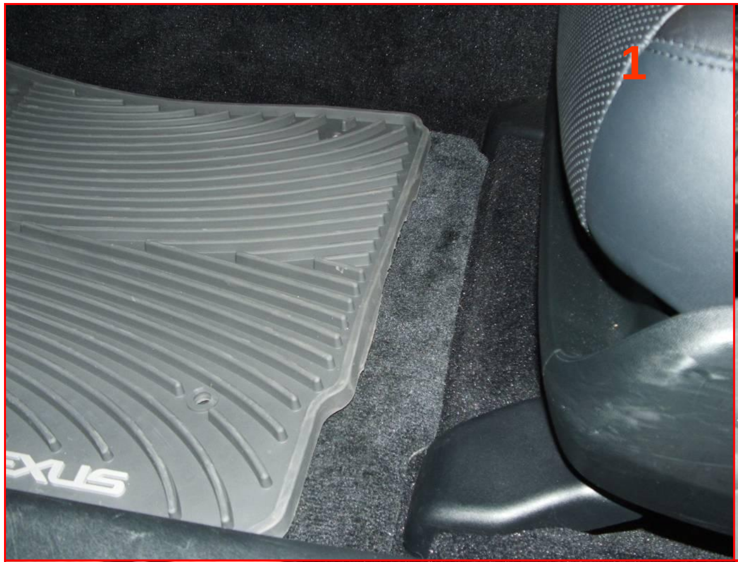
  - Braking capacity (braking torque vs. drive axle torque):
    - High-power engine, high initiation speed, and depleted vacuum reduce brake effectiveness
    - Drivers initially able to manage speed for 1-2 miles, but may not be able to stop
    - Brakes lose effectiveness due to over-heating ⇒ speed ⇑ (some >100mph)

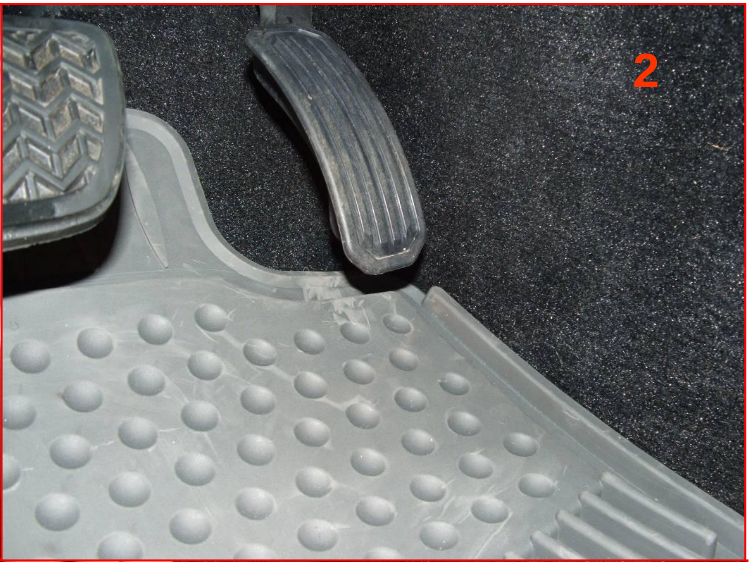
  - Complex PRNDL gate design – difficulty shifting to "N"

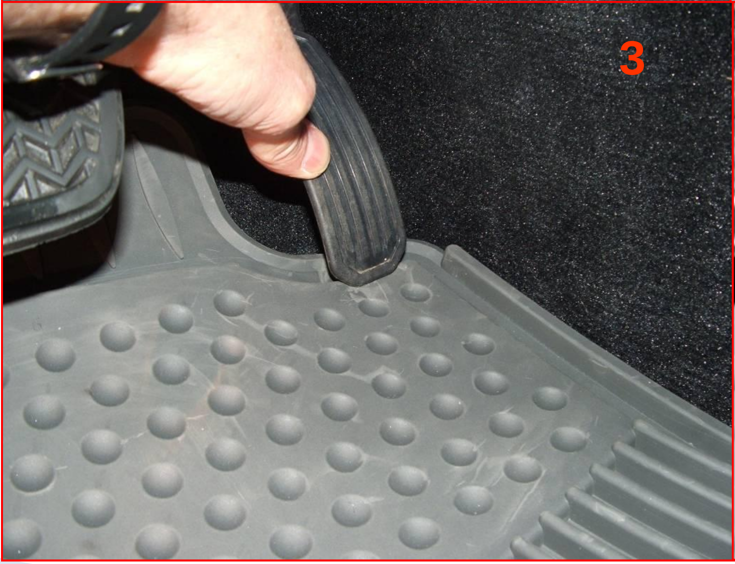
  - Push-button ignition – difficulty turning engine "OFF"

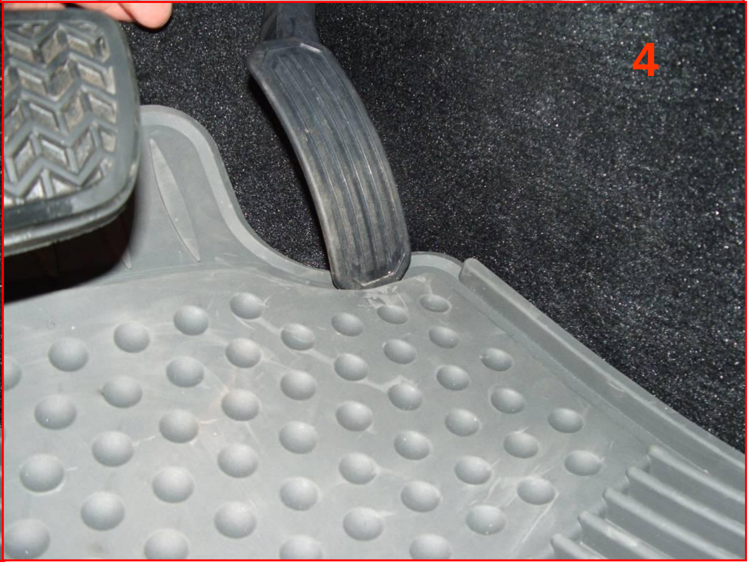
  - See San Diego County Sheriff's Department Incident Report concerning August 2009 crash in Santee, California (Case No. 09056454)

# Pedal Entrapment



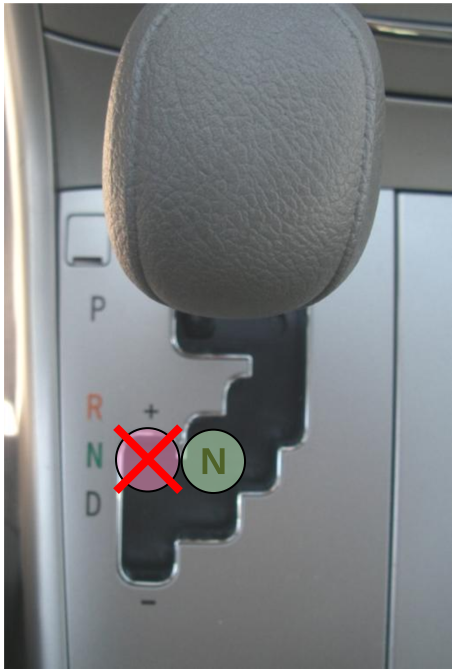


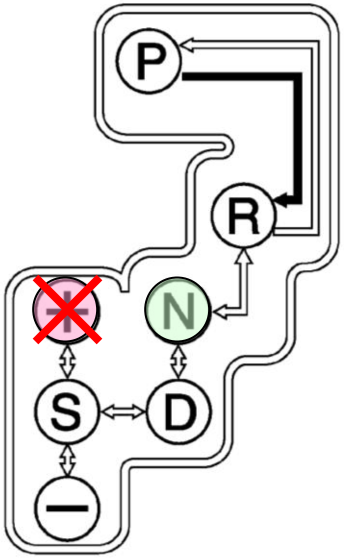




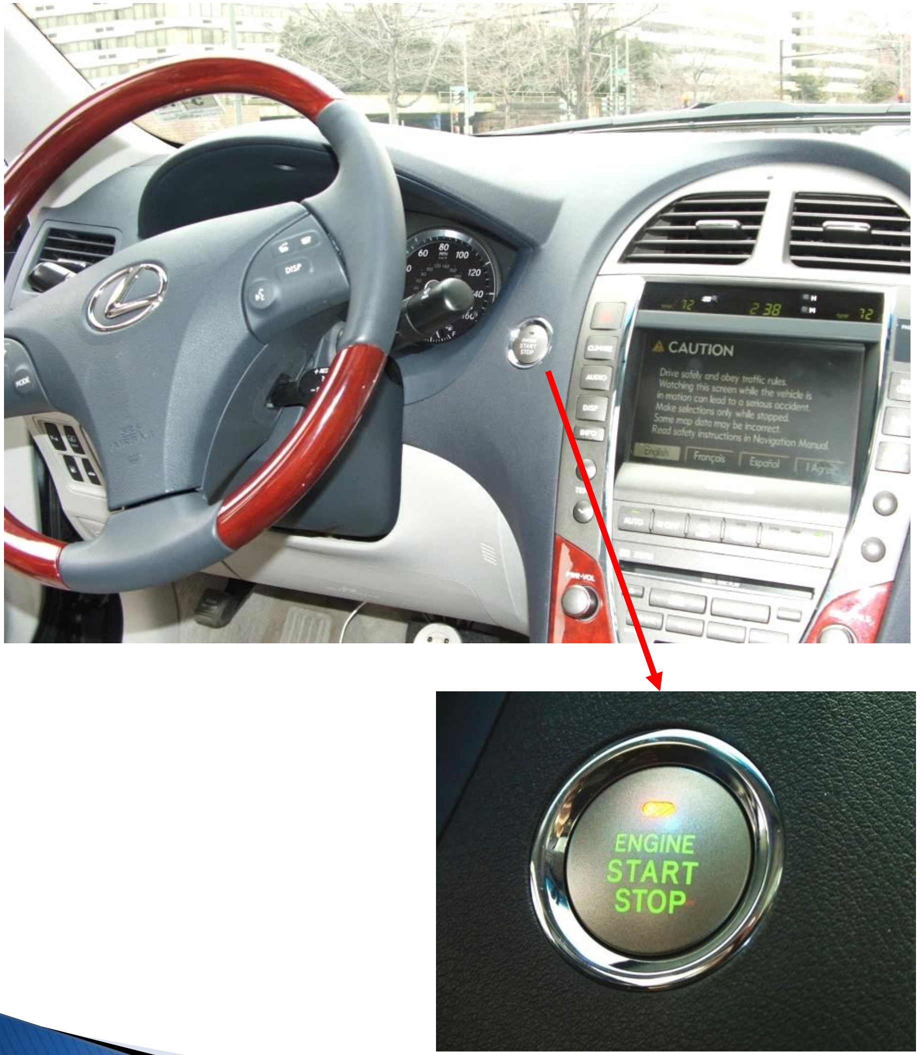
# PRNDL Gate Design

- Drivers may attempt to shift to “Neutral”
  - PRNDL gate design for Toyota Sequential Shift vehicles may not be intuitive for location of “Neutral”
  - Drivers who successfully shift to “Neutral” may misinterpret ⇑ in engine rpm and shift back to drive





# Engine Start/Stop Switch



- Switch operation:
  - Vehicle stationary: momentary press to start and stop
  - Vehicle in-motion: must press and hold for at least 3 seconds (to avoid inadvertent shut-off)
  - Different strategies used by other manufacturers
    - Different time intervals
    - Many included shut-off with multiple press (2x or 3x)
    - Some prevent engine shutoff when moving (and not in PARK)

# Countermeasures

- Brake Transmission Shift Interlock (BTSI)
  - Requires brake application for shift from PARK to ensure safe shift
  - Introduced in U.S. in 1987 Audi passenger cars
  - Implemented in 80% of new cars sold by 1992
  - In vehicles without BTSI, approximately 70% of UA incidents occurred upon shift from PARK to REVERSE or DRIVE
  - Effect on UA experience:
    - When first implemented, vehicles with BTSI experienced about a 60% drop in UA
    - Operating mode changed from P-D or P-R shifts to end-of-trip parking maneuvers in D or R

- Brake Throttle Override (BTO)
  - Reduces throttle opening if the accelerator and brake pedals are depressed simultaneously under certain conditions
  - Ensures that braking torque is greater than drive axle torque
  - Software implementation, only possible in ETC vehicles
  - Each company has different implementation strategy
    - Some depend on sequence of pedal application, vehicle speed, amount of brake application or fixed accelerator position to trigger override
    - Not a solution for all UA

# Defects Investigation Recommendations

- Are there practical ways to improve NHTSA’s ability to find defects that may be based in electronic systems, particularly rare events where physical evidence is not apparent?

# Possible Electronic Causes

**Roger Saul**

NHTSA Vehicle Research and Test Center

**Mike Kirsch**

NASA Engineering Safety Center

# Toyota Electronic Throttle Control (ETC) Study

- Joint NHTSA-NASA effort
  - Specific focus on possible Toyota failure mechanisms leading to UA and warrant opening a defect investigation
    - Identified and demonstrated

- Volpe test plan peer review ~ initiated June 22

# ETC Overall Approach

- Meetings with outside parties
  - Manufacturers and suppliers
  - Individuals
    - Rajkumar, Gilbert, Hubing, Belt, and others
- Complaint data analysis
  - Scope of problem (vehicle models, types of incidents)
- Vehicle characterization testing
- Assessment of ETC System
  - Look for flaws that may be real-world cause of UA
- Determine whether results support opening defect investigation

# Complaint Data Analysis

- Vehicle Owner Questionnaires (VOQ)
  - Auto Safety Hotline, web site, US mail

- Alleged UA consumer complaints encompass variety of situations
  - UA, aggressive cruise control resume, transmission shift surge, etc.

## Examination Past 10 Years VOQs

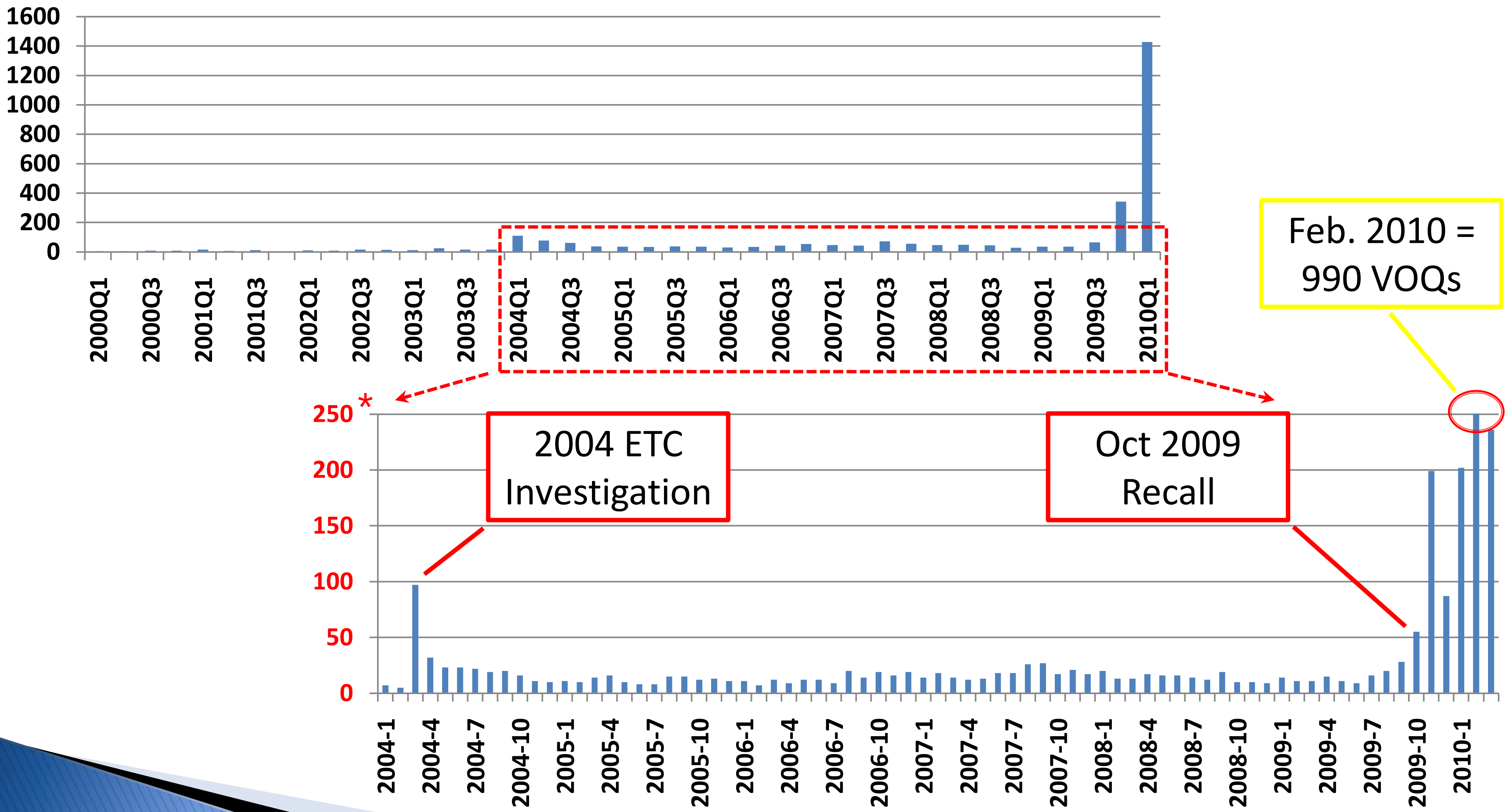
(Mechanical & Electronic Throttles)

| Drilldown to Toyota UA VOQs | No. of VOQs |
|---|---|
| Total VOQs received from 1/1/2000 to 3/5/2010 | 426,911 |
| UA related VOQs ID'd by key-word search | 19,269 |
| VOQs remaining after manual review | 11,454 |
| MY1998-MY2010 - only | 9,698 |
| Toyota - only | 3,054 |

# Publicity Effects of Toyota UA VOQs

**Note: Vehicle-based cause of UA from VOQ statements not confirmed by NHTSA**

3,054 Toyota VOQs by Date of Report



2004 ETC Investigation

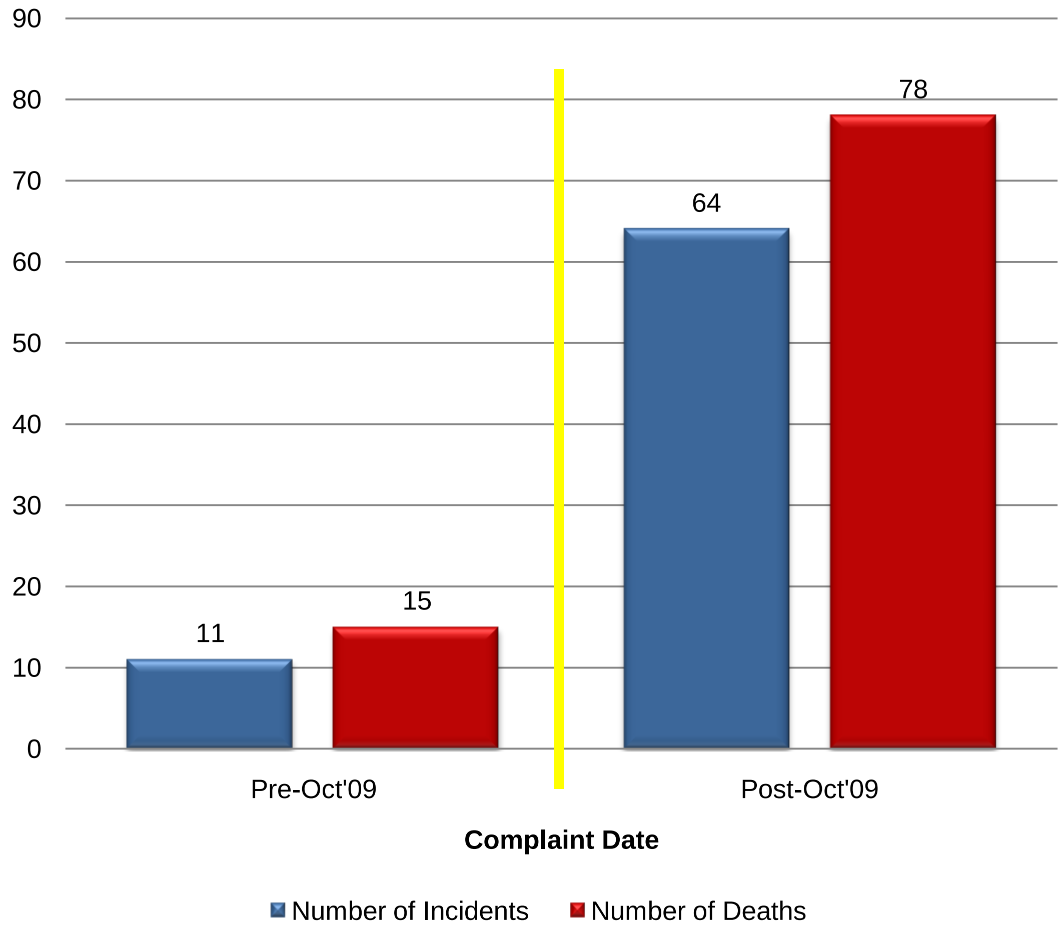
Oct 2009 Recall

Feb. 2010 = 990 VOQs

# Fatal Incidents Allegedly Involving UA in Toyota Vehicles Since 2000

**Post Oct'09 VOQ increase due to recall publicity effect**
**Vehicle-based cause of UA from VOQ statements not confirmed by NHTSA***

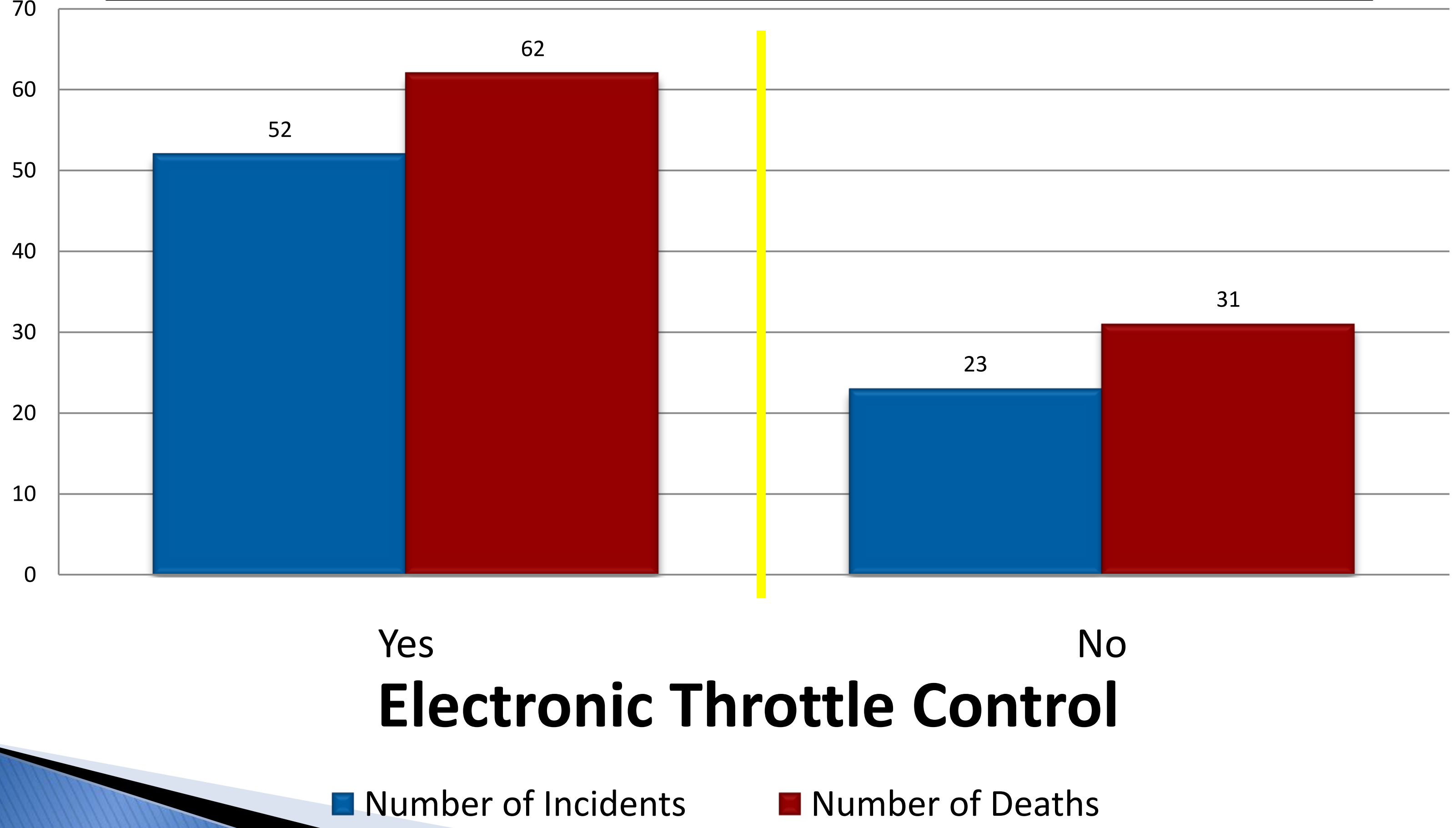
- 75 complaint incidents involving fatality reported
  - 11 prior to Oct'09
  - 64 since Oct'09
- 93 fatalities in these events
  - 15 prior to Oct'09
  - 78 since Oct'09
- *NHTSA confirmed 1 incident of vehicle based cause
  - Involved 4 deaths



# Fatal Incidents Allegedly Involving UA in Toyota Vehicles Since 2000

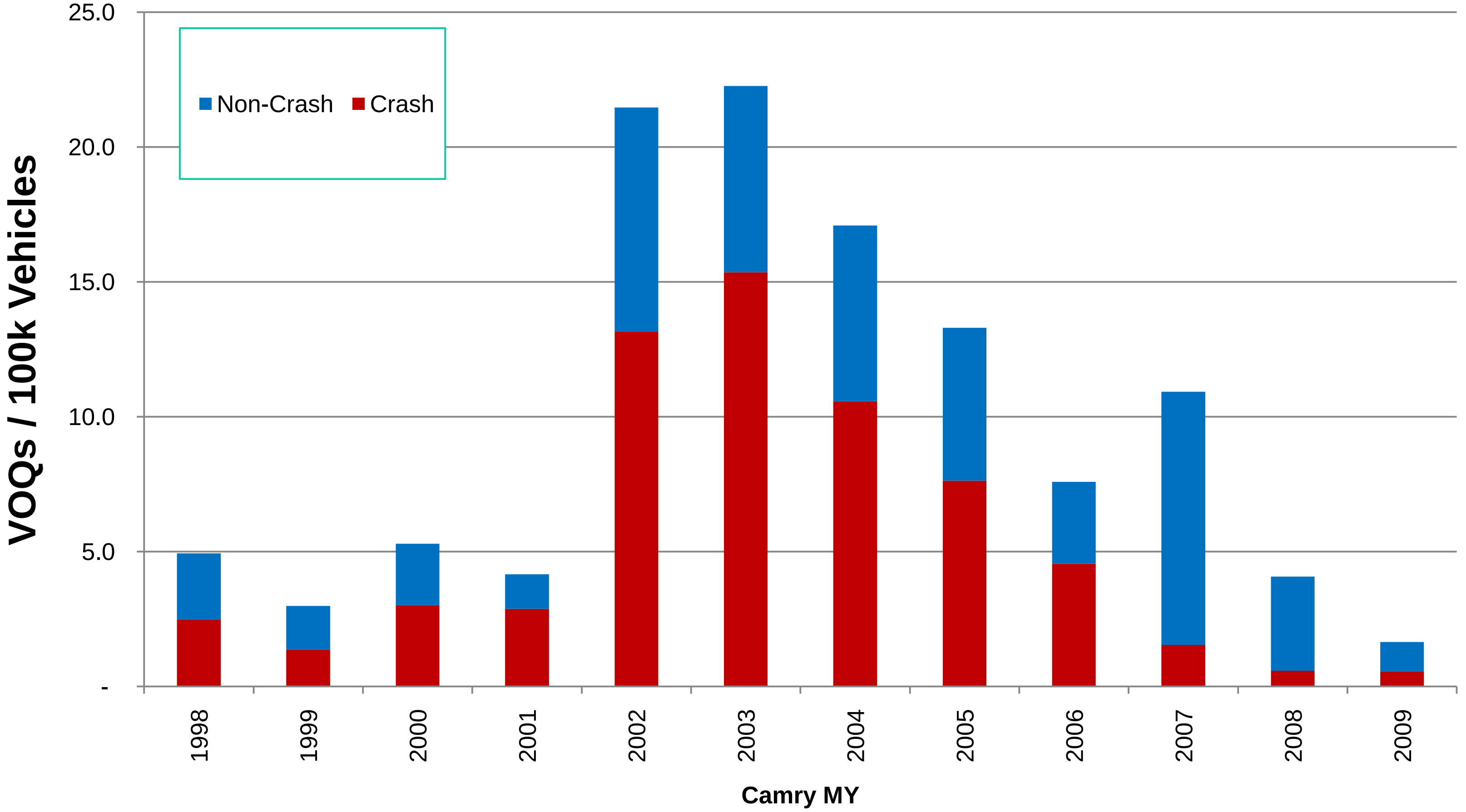
## Electronic vs. Mechanical Throttle

**Post Oct'09 VOQ increase due to recall publicity effect**
**Vehicle-based cause of UA from VOQ statements not confirmed by NHTSA**



# Camry UA VOQ Rate by Model Year

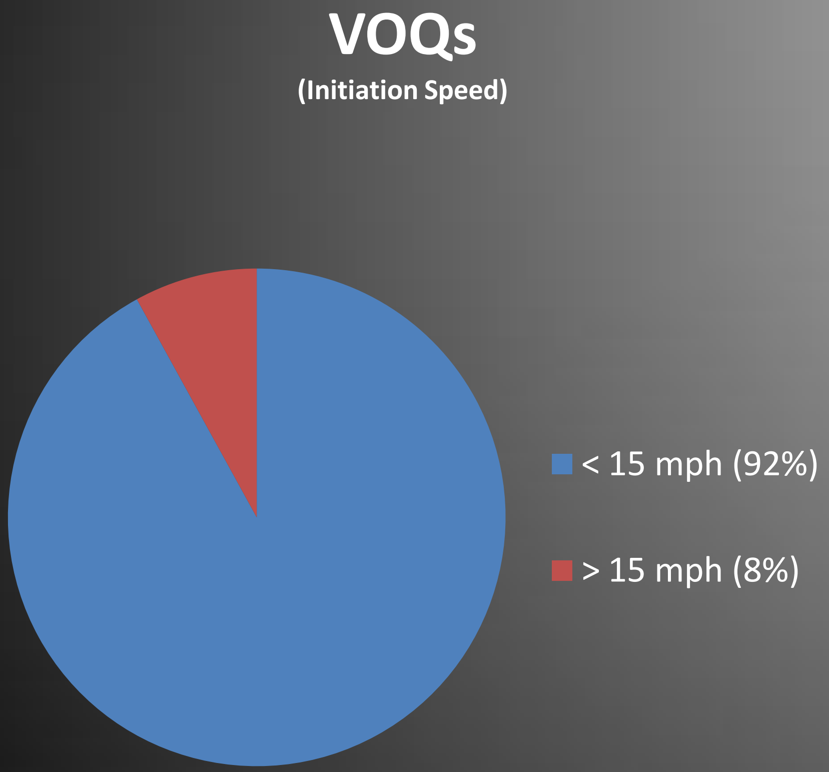
## Pre- 5-Oct-09*

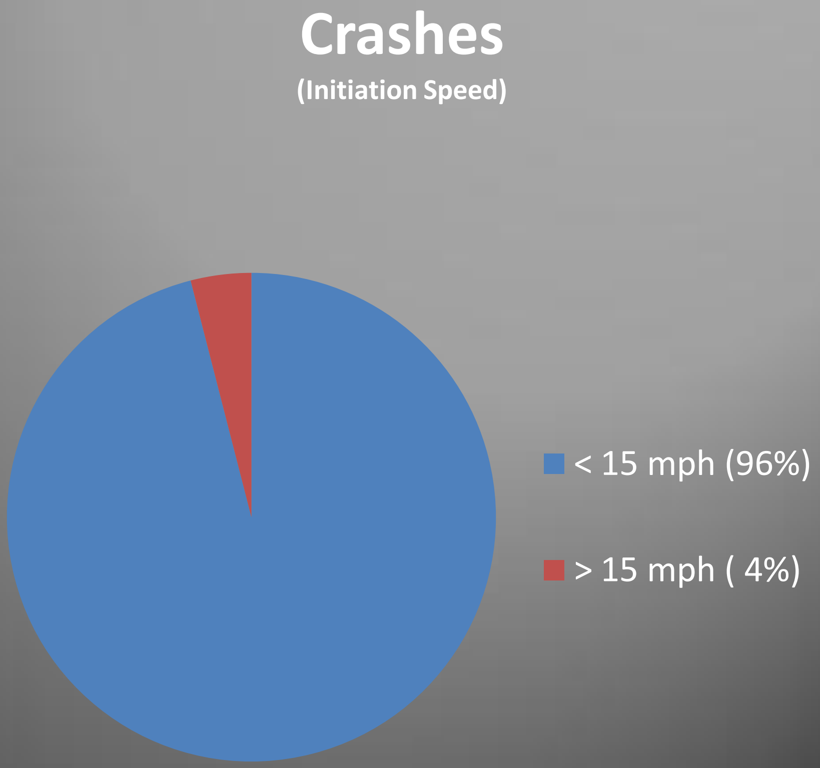


**Gen 5** **Gen 6** **Gen 7**

*Post 10/5/2009 data biased due to recall publicity

# MY 2002 - 2006 Camry UA VOQ’s
## Consumer Complaints by Initiation Speed;
## Pre- 5-Oct-09


**VOQs**
(Initiation Speed)


**Crashes**
(Initiation Speed)

# Test Vehicle Characterization Effort

- Purpose: To document vehicle features and capabilities that may contribute to instances of unintended acceleration
  - Conducted at NHTSA Vehicle Research and Test Center in Ohio

- Vehicle selection
  - Gen 6 Camry designs + Gen 5 & Gen 7
  - Complaint vehicles

- Documentation & characterization
  - Electronic interrogation ~ repair history, TSB servicing, etc.
  - Brake & acceleration assessment
  - Gearshift pattern documentation
  - Pedal design and placement

# Assessment of ETC System (NASA support to NHTSA)

Mike Kirsch
NASA Engineering and Safety Center (NESC)
Principal Engineer

# Scope

- Determine if there are design and / or implementation vulnerabilities in the Toyota electronic throttle control (ETC) system that could realistically be expected to cause unintended acceleration (UA).

# Goal

To Answer:

- What specific conditions are necessary for ETC failure to occur?
- Are those conditions evident in the reported cases to date?
- What physical or electronic evidence does the failure produce?
- What are the expected ranges in severity (throttle opening) and duration that could be caused by the failure?
- Could the failure have any effect on other interfaces, such as the braking system?

# Team Organization

- **NASA Team Leverages Broad NASA Engineering and Safety Center Network of Experts**

- **Participants from:**
  - Ames Research Center, CA
  - Dryden Flight Research Center, CA
  - Goddard Space Flight Center, MD
  - Johnson Space Center, TX
  - Jet Propulsion Laboratories, CA
  - Kennedy Space Center, FL
  - Langley Research Center, VA
  - Marshall Space Flight Center, AL

- **Main themes of the Study**
  - System Engineering and Integration
  - Hardware
  - Software
  - Electromagnetic Compatibility
  - Human Factors

# Points to Consider

- **Automotive troubleshooting is significantly different today than 10 years ago**
  - Hundreds of thousand of lines of software code
  - Much harder to trace symptoms to physical causes

- **NASA has developed a strong systems engineering culture over generations to manage mission success**
  - NASA Spacecraft needs to work the first time

- **NASA is applying this sound systems engineering approach to investigate possible ETC causes of unintended acceleration**
  - Similar to a failure investigation

# Systems Engineering Approach

- Study complaint symptoms and history
- Develop understanding of how the design is supposed to work
- Develop understanding of how the design might fail
- Test for understanding
- Develop Event Sequence Diagrams
- Develop Fault Tree
- Test the vehicle ETC to evaluate scenarios derived from the Event Sequence Diagrams and the Fault Tree

# Path to Vehicle Testing

- System, Hardware, and Software Engineering Analysis will lead to Test Scenarios for evaluation
- Test Scenarios to be evaluated and prioritized by feasibility of the failure and how well the failure behavior matches reported incident reports
- Test Scenarios to be conducted in the lab using bench top subsystem model (825)
- Test Scenarios to be conducted on “non-complaint” vehicle at GSFC
- Test Scenarios to be conducted in collaboration with DOTs Vehicle Research Test Center on other Model Years, and “complaint” vehicles

# Final Points

## Toyota Electronic Throttle Control(ETC) Study

- **Roger Saul**

  NHTSA Vehicle Research and Test Center

# Potential Outcomes of Toyota ETC Effort

1. Identification of possible defect that would warrant opening an investigation

2. Nothing identified that would warrant opening a defect investigation or further inquiry

3. Identification of areas of interest worthy of further review, but without linkage to real-world events necessary to open a defect investigation

# Final Report

- NASA will report to NHTSA on its findings and recommendations
- NHTSA will issue a final report summarizing entire project and explaining its planned follow-up actions
- Findings will inform future NHTSA Research of vehicle electronics, software, and emerging technologies
- Results provided to NAS review of electronic control issues across the industry

# ETC Wrap-up and Recommendations

- Goal: Assure the future safety of electronic throttle control system

**Recommendations**

- Broad review of electronic systems and UA
  - Are improvements needed in systems design approach regarding software, hardware, electronics and controls?
- Methodology for assessing potential electronic failures & risks
- Limitations of testing for rare events

# Human Factors Considerations: Unintended Acceleration & Pedal Errors

- Richard P. Compton

  Director Office of Behavioral Safety Research

# Overview

- Human factors are a contributing factor in more than 90 percent of all crashes
- Human error plays a role in some UA incidents
- Likely causes of UA-related human error
- Current NHTSA study on pedal errors (began in 2008)

# NC Study of Pedal Errors

Pedal Error is a known contributor to crashes, e.g.:

- A study of 219 crashes in North Carolina's crash database in which the driver's foot contacted the accelerator rather than the brake
  - Most misapplications
    - Occurred during driving cycle – not at startup
    - Were not hurried
  - About half resulted from the driver's foot slipping from the brake to the accelerator (Schmidt, Young, Ayres & Wong, 1997)

# How Common is Pedal Misapplication?

Not known precisely, but consider:

- Over 200 million licensed drivers
- One trip a day = 200 million trips
- Assume 50 brake applications per trip

Result: **10 billion** opportunities a day for error to result in misapplication

# NTSB Investigations of UA Crashes

NTSB has investigated a number of unintended acceleration crashes

- Reports include details about driving experience; medical, vehicle, and environmental factors
  - Between 1997 and 2008, NTSB investigated 7 unintended acceleration crashes
    - 1 passenger car
    - 5 buses
    - 1 fire truck
  - In each instance, investigators determined that the crashes resulted from the driver’s pedal error

# Recent Reports on Pedal Errors

- *In my car the brake is on the right: Pedal errors among older drivers* (Freund, Colgrove, Petrakos & McLeod, 2007)
  - Study to assess extent specific cognitive functions contribute to pedal errors among older driver
  - 180 subjects drove a driving simulator
  - Suggests executive dysfunction contributes to pedal errors in older drivers.

# Apparent Overrepresentation in Pedal Error Crashes

Based on available literature:

- Drivers of unfamiliar vehicles (NTSB, Pollard and Sussman, 1989)
- Younger drivers
  - Have limited driving experience, so may be less familiar with brake position
  - Have not fully developed the prefrontal cortical structures that facilitate overriding an incorrect response (Lococo and Tucker, in press)
- Older drivers
  - May experience age-related declines in these structures (Lococo and Tucker, in press)

# Likely Causes of Pedal Misapplication

- The driver correctly selects the brake

- Variability in the processes that determine the trajectory and endpoint of the movement
  - Driver turning to check the side mirror or look over their shoulder – results in error in foot placement, particularly if the driver's response is forceful

- Rarely, the driver's foot hits a point a bit to the right of the brake – the accelerator

# Variability in Behavior

- Schmidt (1989) explored the relationship between driver's movement control and unintended acceleration to determine:
  - Source of foot placement errors
  - Why a driver would fail to immediately perceive the error
  - Why a driver would persist in pressing the wrong pedal for several seconds or more

# Variability in Skilled Performance

# Movement Error Research

- Focused on arm and hand movements, but findings should apply to leg and foot movement
  - Larger limbs showed more trajectory variability (Langolf, Chaffin & Foulke, 1976)
  - Accuracy in acquiring an unseen target declined substantially when participants turned their heads (but not their gazes) by 10 – 30°.

# Failure to Correct

- Drivers brake successfully on a regular basis – the driver is confident that he or she can brake accurately, even without confirmatory feedback

- Driver confidence that the foot is on the brake makes it difficult for the driver to detect and respond appropriately when the foot is actually on the accelerator

- The driver is convinced that his or her foot is on the brake, and may “brake” more firmly, exacerbating the situation

# Possible Causes of Failure to Correct

- Why do drivers sometimes persist in pedal errors – for more than a few seconds ?
  - **Hypervigilance** – response to an event that is
    - Strong, startling
    - Potentially life threatening
    - Must be addressed immediately

# Hypervigilance

- Hypervigilance may result in:
  - Impaired information processing
  - Failure to recognize appropriate solutions such as turning the car off, putting it in neutral or applying the hand brake
  - Distraction by a variety of stimuli
  - Vacillation among a range of potential responses (Janis & Mann, 1977)

# Perceptual Narrowing

- Stress narrows attentional focus to highly relevant events, reducing the ability to address unlikely peripheral events (Weltman & Egstrom, 1966)
- Driver ignores the odd feel of the “brake” and instead focuses on the more central events associated with the unexpected vehicle response
- Consistent with driver **perseverance** in the error and with drivers’ reports that they “just froze”

# Current Work on Pedal Errors in Older Drivers

- NHTSA has a study underway to explore the current frequency of pedal application errors in older drivers

- Planned and initiated several years ago

# Objectives

- Determine the extent of pedal error crashes
- Identify groups overrepresented in these crashes –
  - Novice drivers?
  - Older drivers?
- Identify typical situations/circumstances

# Literature Review

- Technical literature

- News media reviews
  - Pedal error crashes in the US between 2000 and 2010
    - Searched for key phrases in newspapers (daily, weekly), TV and radio broadcast transcripts, news wire services, internet media

- Limitations of media reviews
  - No control over which crashes were reported
  - Reports are sometimes purged from archives due to space limitations
  - Whether a crash was reported might be influenced by other newsworthy events
  - These crashes may be more newsworthy in some locales than others
  - Not all publications provide their full text articles to Lexis-Nexis, America's Newspapers, and Google News

# News Media Interim Results: Driver Age

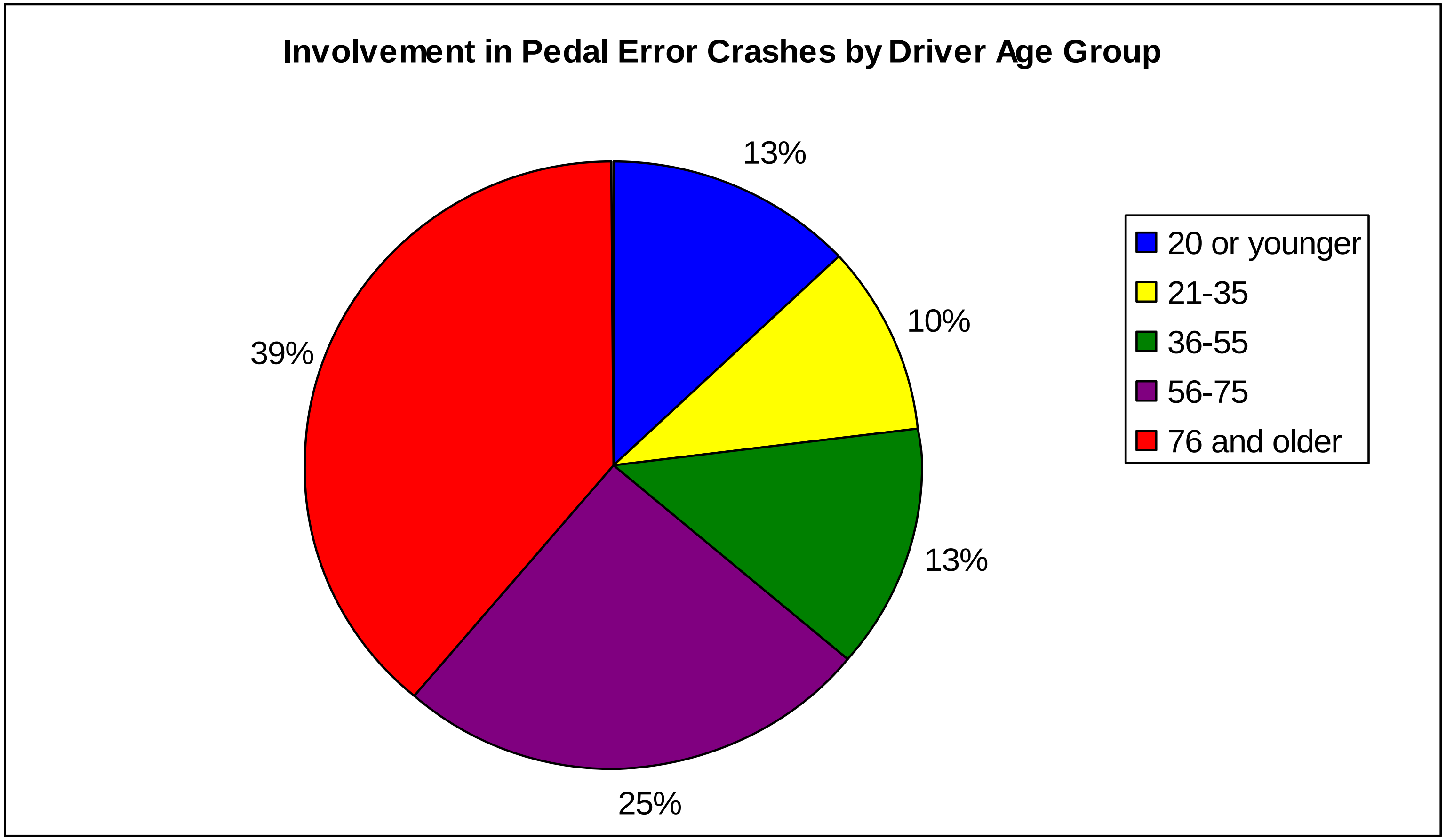
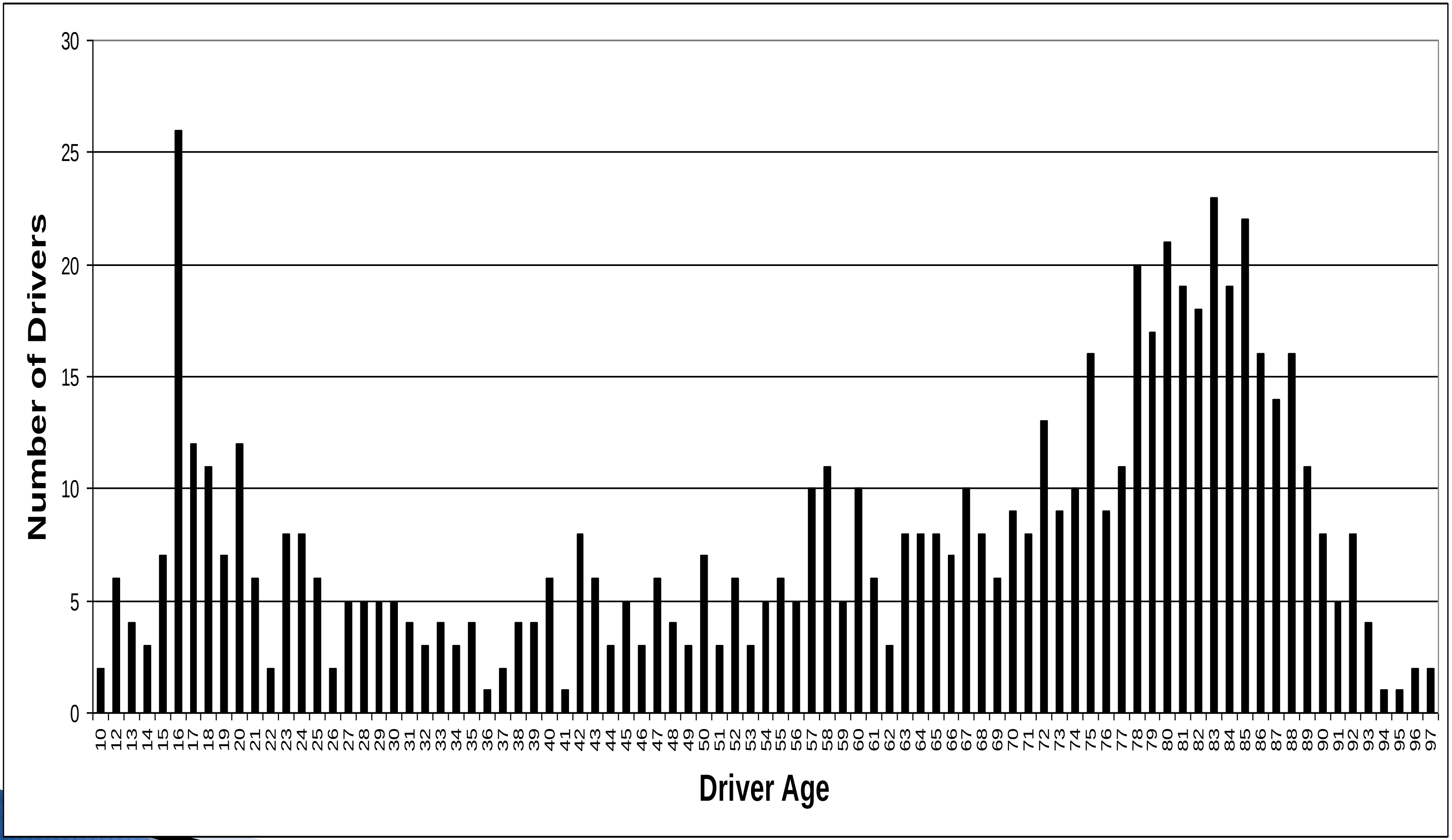


**Figure 1. Involvement in Pedal Error Crashes by Driver Age Group (n=683).**

# Interim Results: Driver Age



# Interim Results: Location

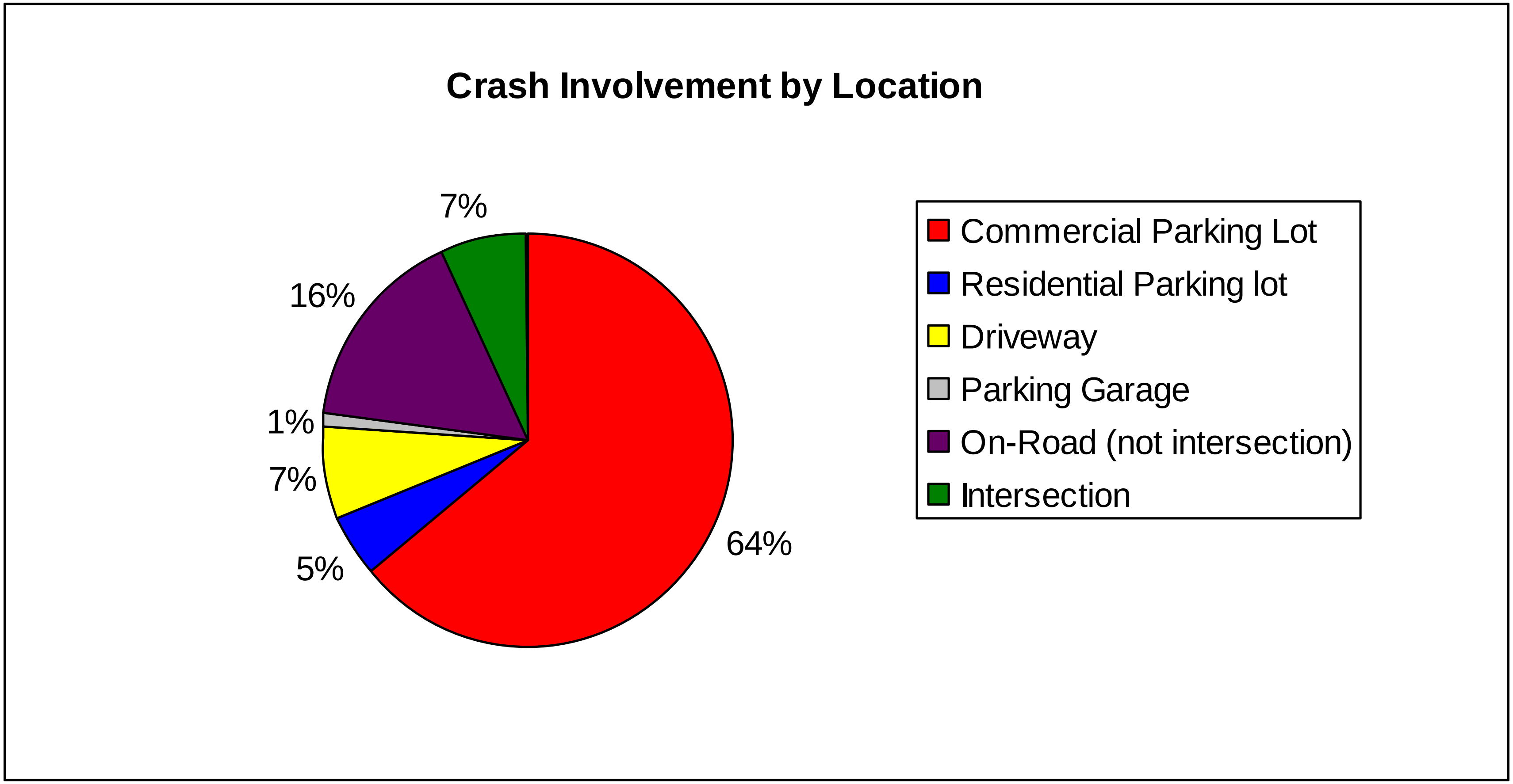


**Figure 3. Crash Involvement by Location (n=861).**

# Interim Results: Pre-crash Maneuver

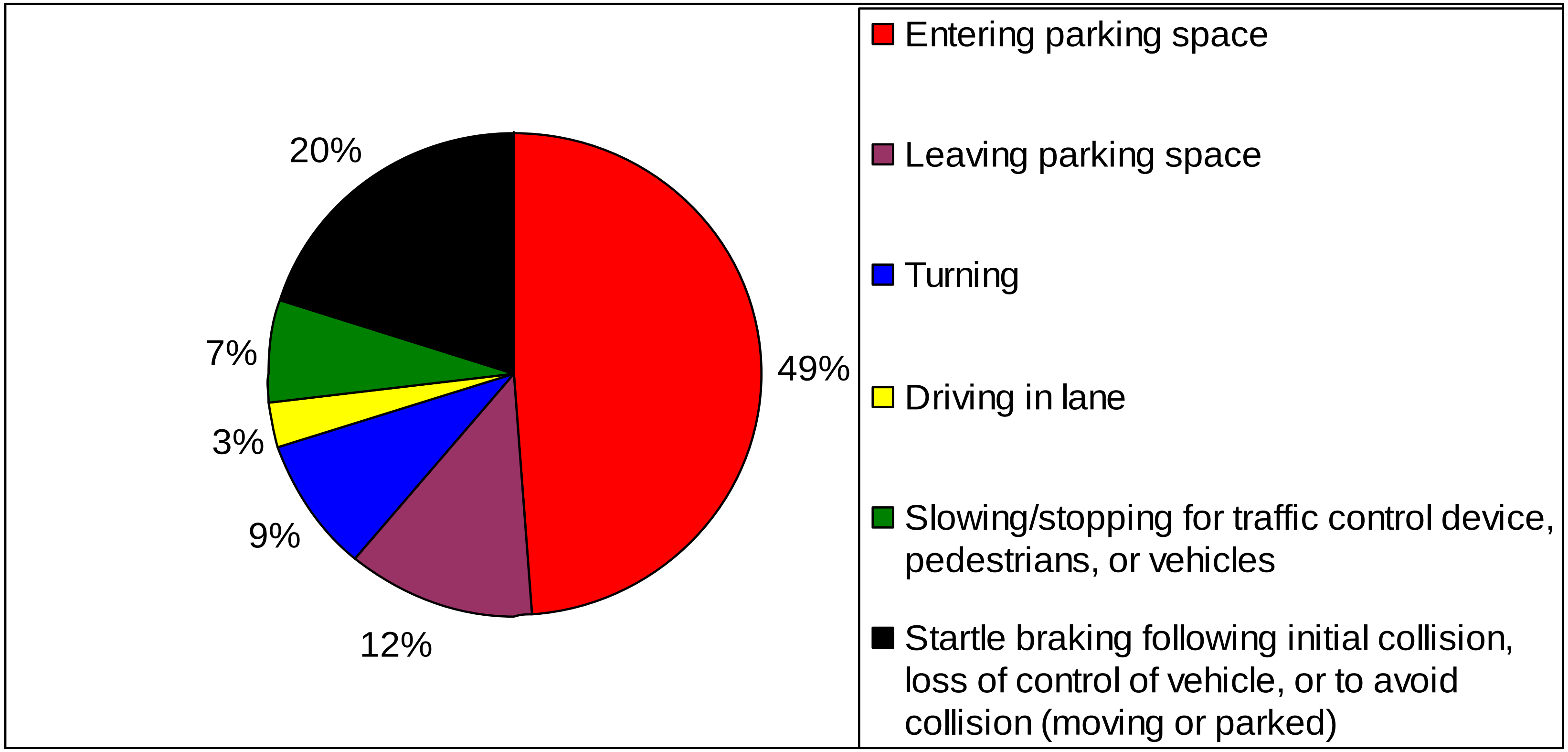


**Figure 4. Prevalence of Pre-Crash Maneuvers, Collapsing Slowing/Stopping Categories and Startle Categories (n=661).**

# Conclusions

- Human error is one important cause of unintended acceleration
- Human performance is variable; people make mistakes
  - Pedal error is understandable
  - Failures in error detection and error correction need to be addressed
- How this panel can help:
  - Address human error as a cause of UA
  - Determine whether electronic controls affect prevalence of pedal error
  - Make suggestions for reducing likelihood or effect of pedal error through (a) vehicle design, and (b) behavioral training and adjustment

# Government and Voluntary Standards as They Relate to Unintended Acceleration

- Nat Beuse
  Crash Avoidance Standards
  Rulemaking

# Overview

- Review related standards
  - US standards for Throttle Control, Brake Transmission Shift Interlock, Keyless Ignitions, Gear Selector
  - Provide references to related Industry and Non-US government standards
- Current Activities

# Glossary of Terms

- Government
  - FMVSS – Federal Motor Vehicle Safety Standard
  - CMVSS – Canadian Motor Vehicle Safety Standard
  - ECE – United Nations Economic Commission for Europe
  - EU – European Union
- Industry
  - SAE – SAE International
  - ISO – International Organization for Standardization

# Standards Related to Throttle Control

- FMVSS 124 "Accelerator Control Systems"
  - Throttle must return to idle position if there is a disconnection.

  - Does apply to electronic throttles
    - Disconnections may include separations of electrical connectors or conductors linking the accelerator pedal with the ECU and the ECU with the throttle actuator on the engine

  - Canadian Standard is identical.

  - There is a standard in Korea but to our knowledge no other standards for throttle control on passenger cars.

# Brake Transmission Shift Interlock

# Brake Transmission Shift Interlock

- Helpful from “Park” position

- Congress has required all light vehicles to be equipped with BTSI by September 1, 2010.
  - NHTSA has placed the requirement in FMVSS 114.
    - System must function in any key position

- To our knowledge there are no other standards for BTSI.

# Keyless Ignition-Push Button Start

# Standards Related to Keyless Ignitions

- Labeling - FMVSS No.101, “Controls and displays”
  - Button must be labeled “Engine Start” or Engine Stop”
  - Manufacturers can add text or graphics to the required label.
- Operation - FMVSS No. 114, “Theft protection and rollaway prevention,”
  - Can not start the car without the key (theft), and
  - Key cannot be removed unless the vehicle is in Park (rollaway prevention).
- Canadian Standards are identical in these provisions
- There are applicable ISO, ECE, and EU standards. Also an SAE standard is under development

# Gear Selection Control

# Standards Related to Gear Selection

- FMVSS No.102, "Transmission shift position sequence, starter interlock, and transmission braking effect."
  - Neutral must be located between forward and Reverse on passenger cars.
  - On steering column mounted controls movement from Neutral to forward is clockwise and Park is located at the end adjacent to Reverse.
  - Identification of shift positions, in relation to each other and the position selected, must be displayed in view of the driver.
  - Canadian standard is identical.  There is an applicable SAE standard.

# Standards Related to Gear Selection

- FMVSS No. 101, “Controls and displays”
  - P, R, N, D, and L are separate identifiers
  - PRNDL must be illuminated
  - Canadian Standard is identical
  - To our knowledge there are no other standards similar to this labeling requirement.

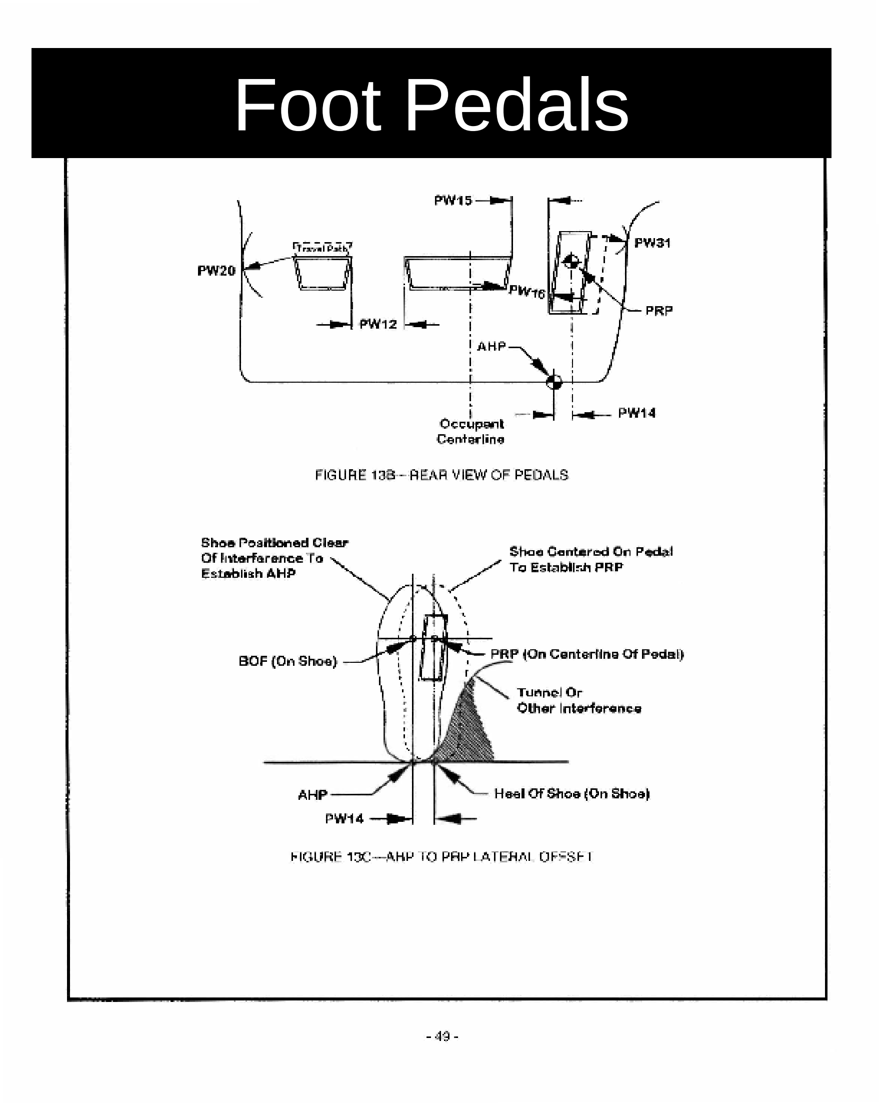
# Current Activity

# Current Regulatory Activity

- FMVSS No. 124
  - Finalizing new tests for hybrid vehicles, electric vehicles, and diesels
- Brake Throttle Override/Smart Pedal
  - Conducting testing to determine performance differences between manufacturers
  - Developing test procedures
- Keyless Ignitions
  - SAE is working on a consensus standard for the operation of keyless ignitions.
    - Work being performed by a subcommittee of the Controls and Displays Committee within the Motor Vehicle Council

# Current Regulatory Activity

- The agency is conducting research in this area.
  - We will be evaluating manufacturers internal guidelines and the applicable SAE and ECE standards



## Foot Pedals

PW15
Travel Path
PW20
PW31
PW16
PRP
PW12
AHP
PW14
Occupant Centerline

FIGURE 13B—REAR VIEW OF PEDALS

Shoe Positioned Clear Of Interference To Establish AHP
Shoe Centered On Pedal To Establish PRP
BOF (On Shoe)
PRP (On Centerline Of Pedal)
Tunnel Or Other Interference
AHP
Heel Of Shoe (On Shoe)
PW14

FIGURE 13C—AHP TO PRP LATERAL OFFSET

- 49 -

# Summary

- What additional steps are recommended to ensure the safety of throttle controls?

- Are additional standards necessary to mitigate UA events?

- The industry standards for foot pedals are design specific and very similar.  Can they be made to be more performance based and are there significant differences between approaches?

- What best practices from other sectors are applicable to vehicle electronics?

# Research Activities Related to Electronics

- John Maddox
  Associate Administrator
  Vehicle Safety Research

# Vehicle Electronics – Research Activities

## Overview

- Current Research Activities
- Evolving New Activities
- Potential Future Directions

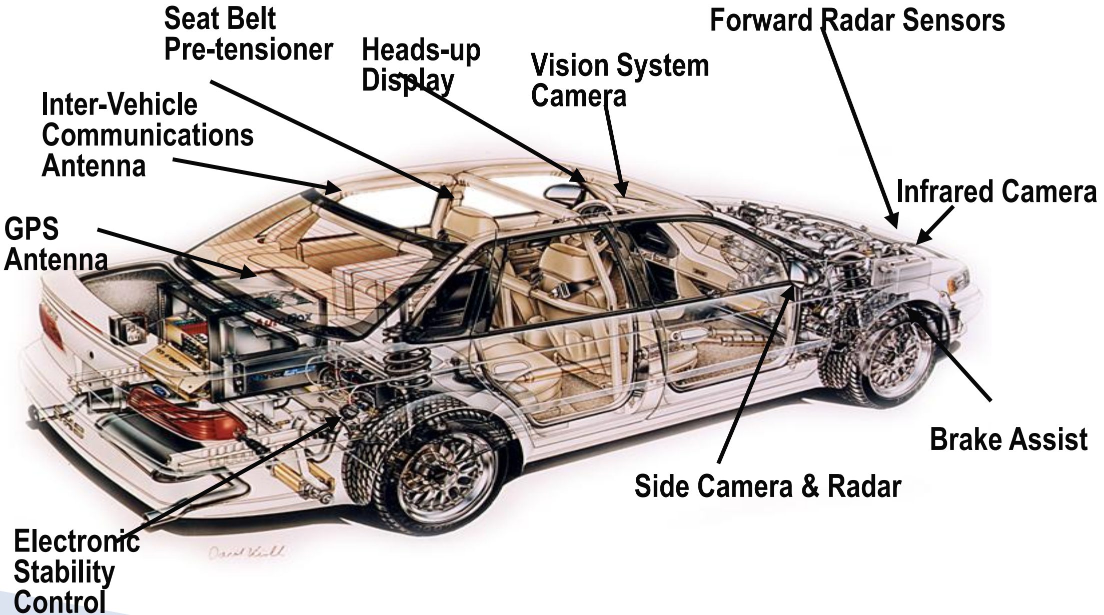
# Vehicle Electronics – Research Activities

- Vehicles are already full of electronic content and features

- Provides increased functionality for customer
  - Powertrain control
  - Restraints
  - Communications
  - Infotainment
  - ….

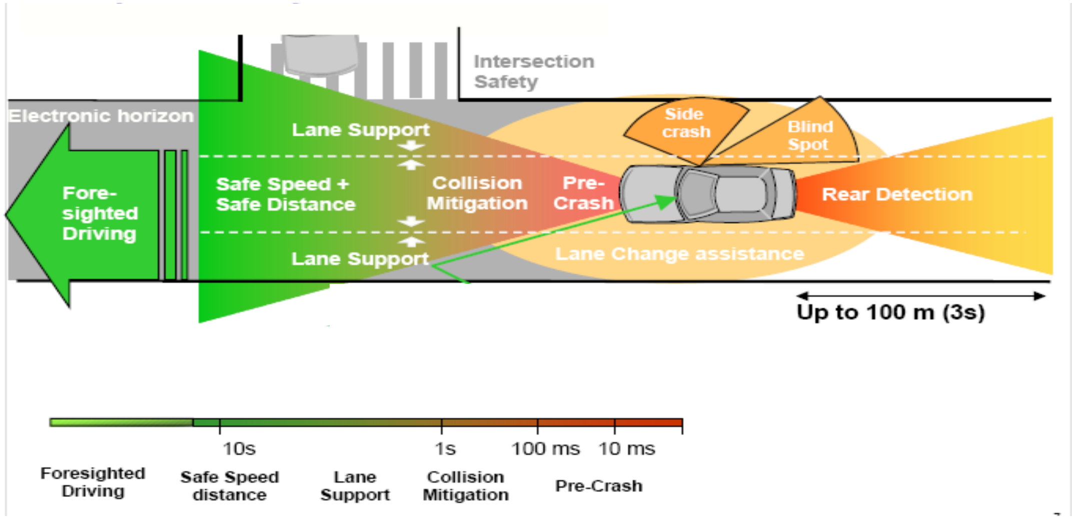
# Vehicle Electronics – Research Activities

- Migrating to Fundamental Vehicle Controls
- Can provide increased functionality for customer
  - ABS, ESC, Brake Assist, Crash-Imminent-Braking…
  - Electronic Throttle
  - Electric Power Steering Assist, Active Steering…



# Vehicle Electronics – Research Activities

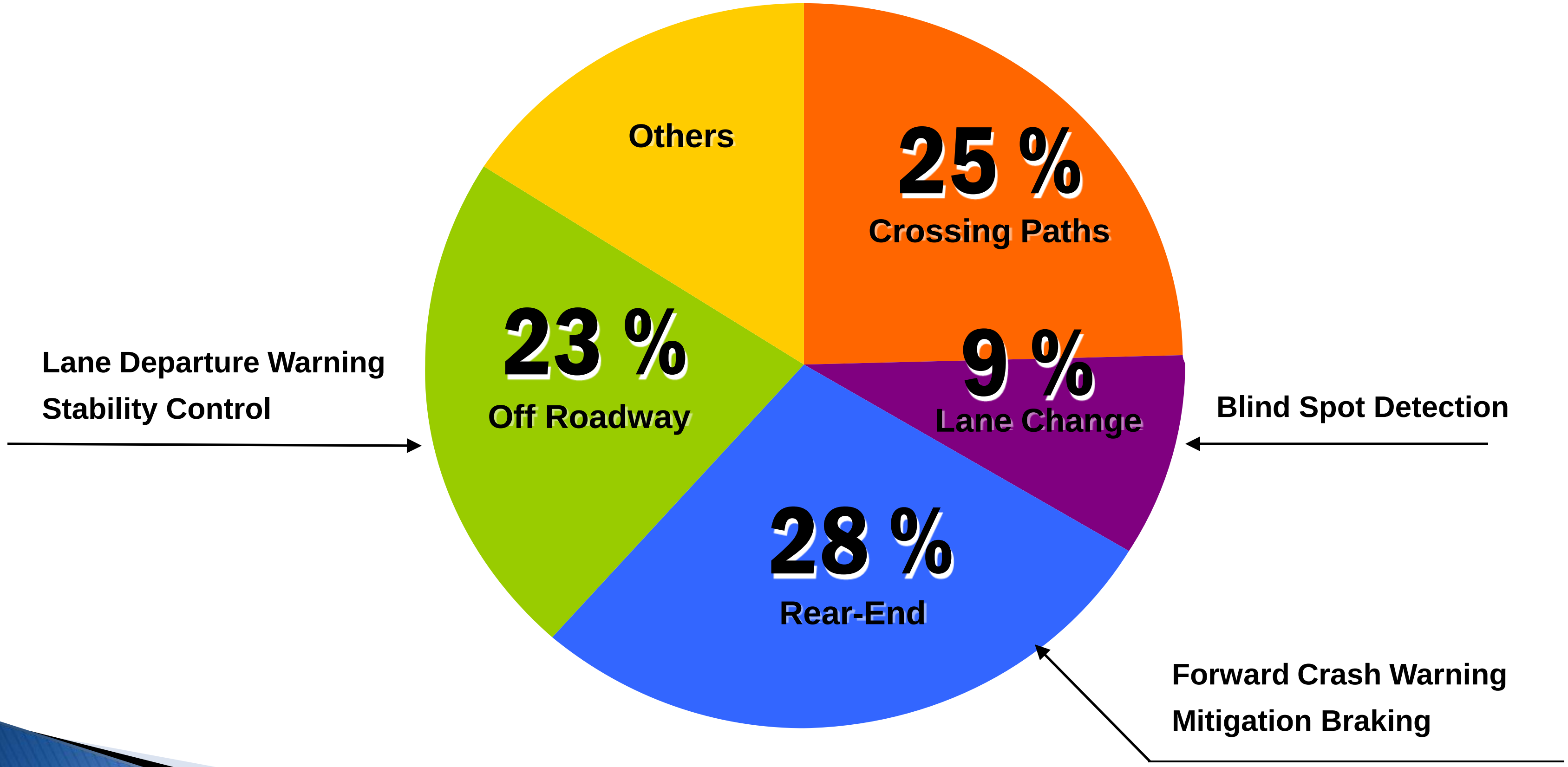
- Crash avoidance technologies are here & growing rapidly
  - Forward collision requires throttle & brake by wire
  - Some lane keeping systems use electric steer assist
  - All use radar and/or machine vision
  - Rely on very complex software & control strategies
- Evolving rapidly



# Crashes of all Severities

## 2007 GES

Vehicle Based Crash Avoidance Systems are being introduced, which can address a portion of Crash Scenarios



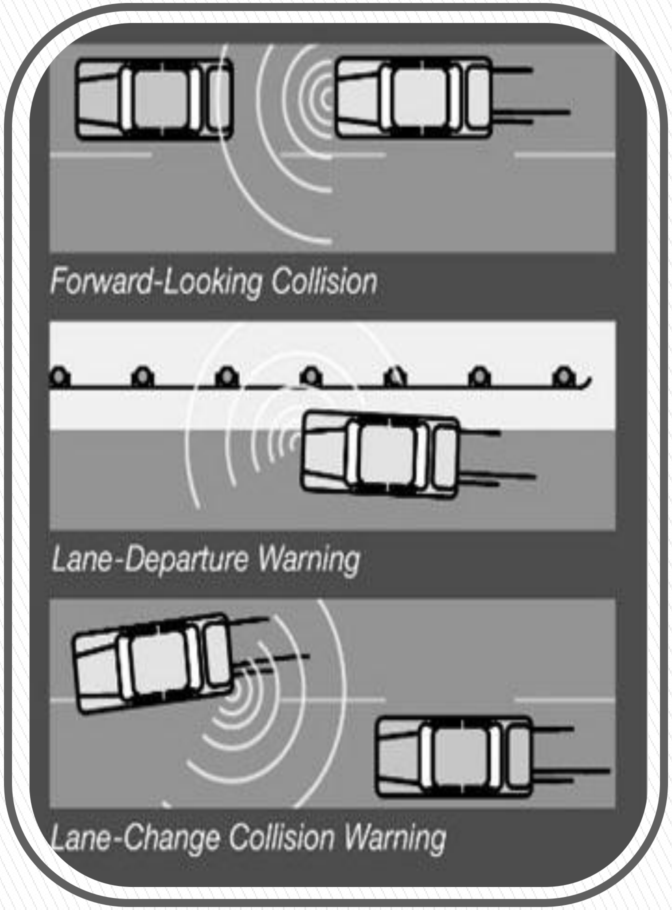
**Lane Departure Warning**
**Stability Control**

**Blind Spot Detection**

**Forward Crash Warning**
**Mitigation Braking**

# Integrated Vehicle-Based Safety Systems

- Purpose: Study effectiveness & driver acceptance of crash avoidance technologies
- Phase 1 - Completed
  - Developed and validated prototype Light and Heavy Vehicles with Integrated Safety Systems
- Phase 2 - Underway
  - On road testing – completed
    - 16 Passenger Cars & 10 Tractors
    - Measuring Driver Acceptance & Safety Benefits
- Analyzing data and summarizing findings
- Will inform future agency activities

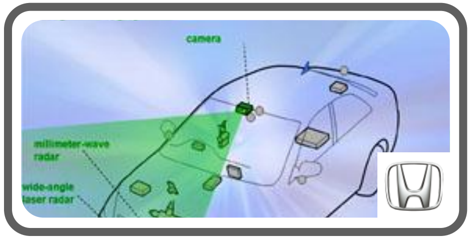


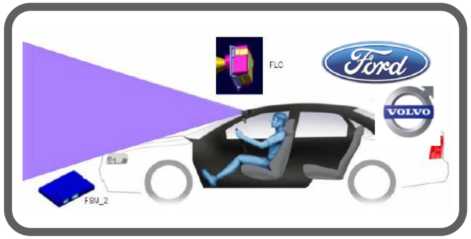
# Advanced Collision Avoidance Technologies (ACAT)

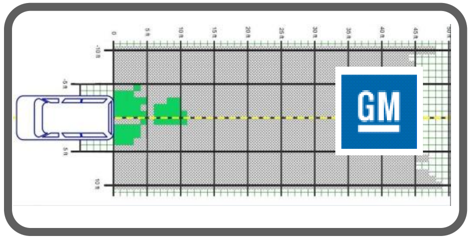
- Purpose: Develop methodologies to estimate the benefits of new and emerging safety technologies

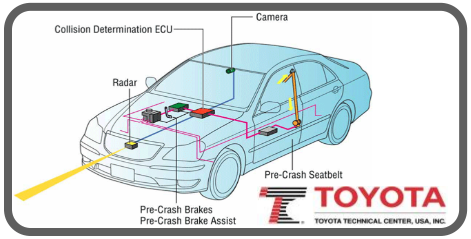
- Research Questions:
  - What safety technologies are available?
  - In what situations do they work?
  - How effective are they?

- Status:
  - Objective Tests Developed
  - Preliminary Safety Benefits Tools Completed
  - Completing Testing and Benefits Estimates
  - Initiating Second Phase
    - Add New Technologies
    - Integrate Benefits Methodologies





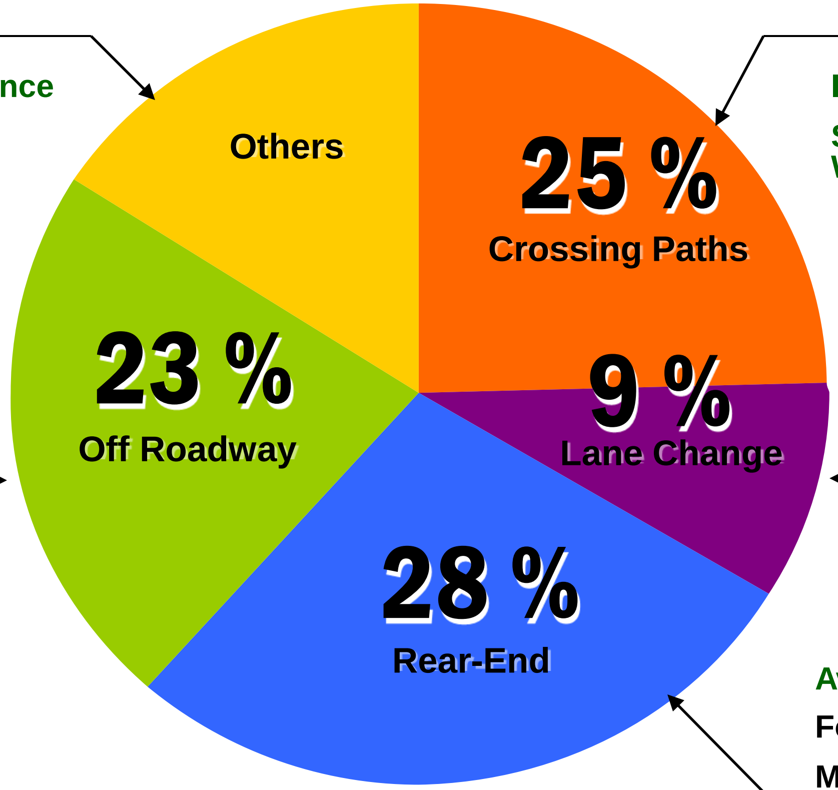




# Crashes of all Severities
# 2007 GES

Communicative Crash Avoidance Systems can address

82% of Crash Scenarios



Head-on Collision Avoidance

Intersection Movement Assist

Stop Sign & Signal Violation Warnings

Curve Speed Warning

Lane Keeping

**Lane Departure Warning**

**Stability Control**

Lane change and merge assist

**Blind Spot Detection**

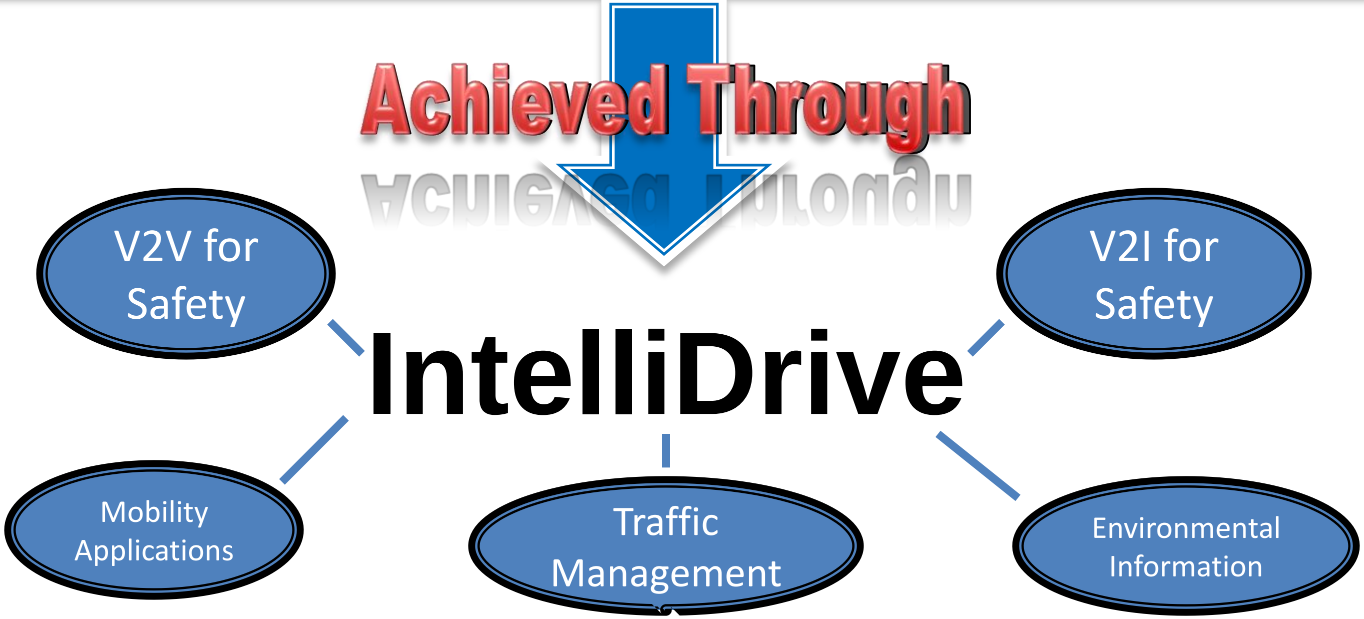
Avoidance Braking

**Forward Crash Warning**

**Mitigation Braking**

# IntelliDrive Program

**A national, multi-modal surface transportation system that features a connected transportation environment among vehicles, the infrastructure, and portable devices to serve the public good by leveraging technology to maximize safety, mobility and environmental performance**



Achieved Through

IntelliDrive

V2V for Safety

V2I for Safety

Mobility Applications

Traffic Management

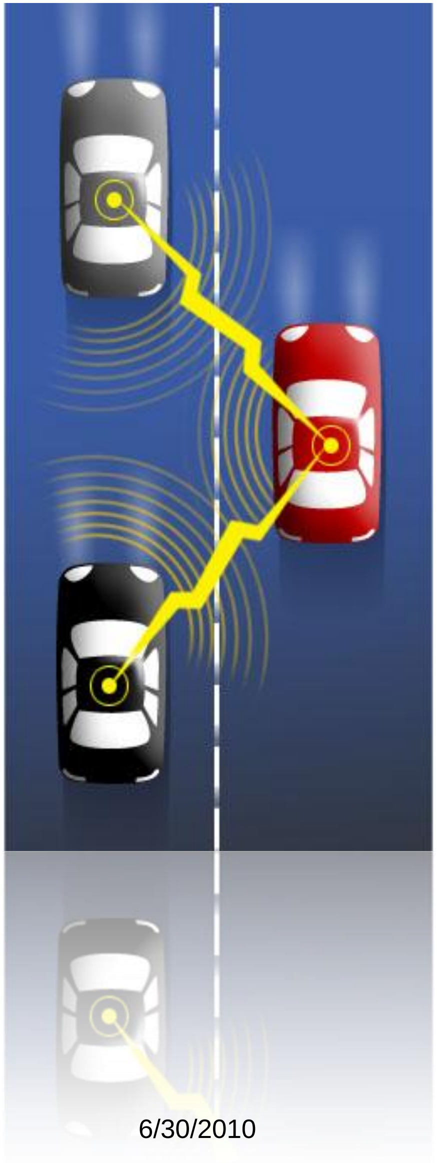
Environmental Information

**…and a suite of targeted research and development initiatives that support cross-modal ITS solutions**

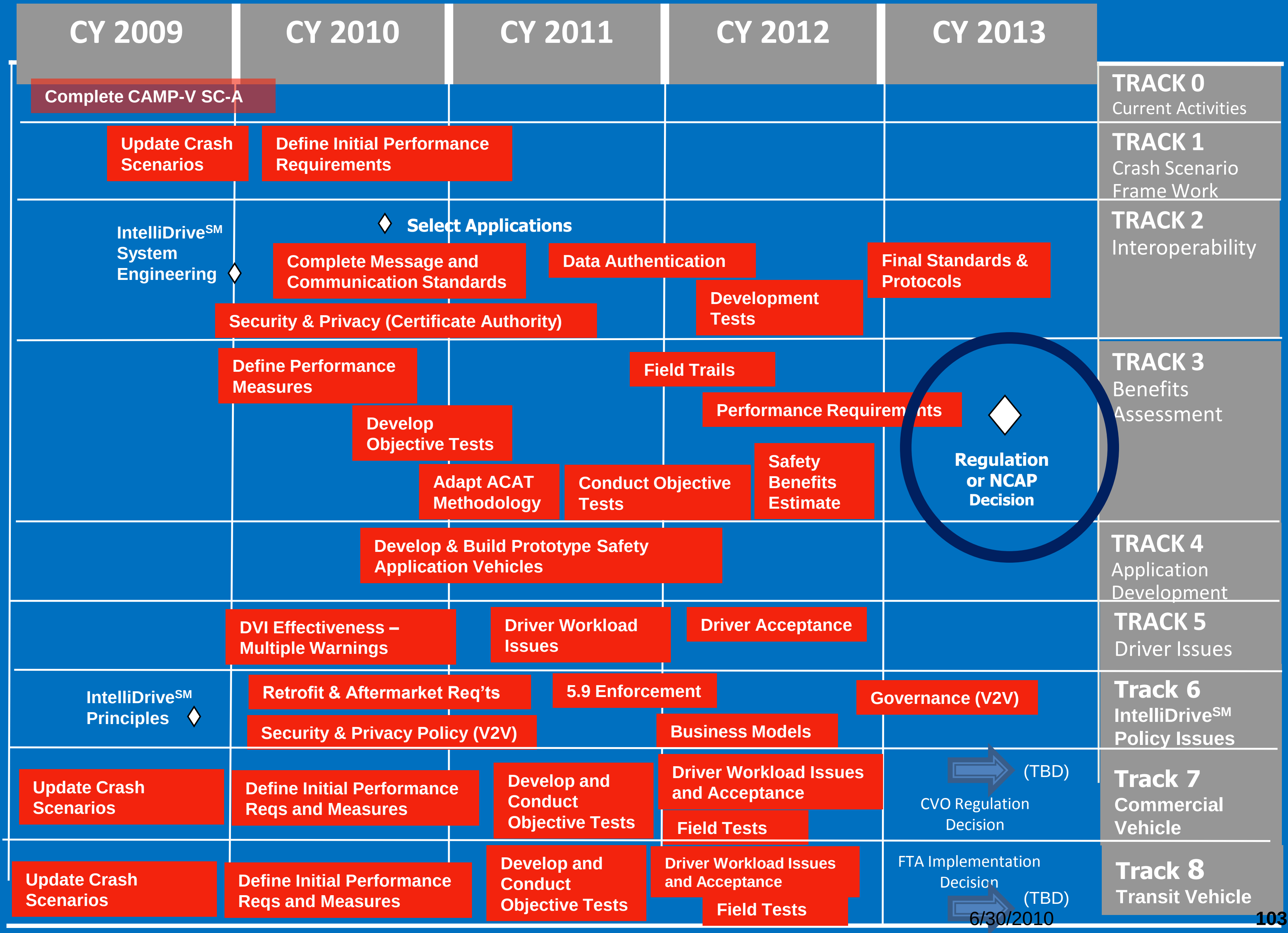
# V2V - Vehicle to Vehicle Communications

- Initial Safety Applications
    - Emergency Electronic Brake Lights
    - Forward Collision Warning
    - Blind Spot Warning
    - Lane Change Warning
    - Do Not Pass/On-Coming Crash Warning

- Many other Safety and Mobility applications possible



# Vehicle to Vehicle Safety Application Research Plan



CY 2009 | CY 2010 | CY 2011 | CY 2012 | CY 2013

**TRACK 0**
Current Activities

Complete CAMP-V SC-A

**TRACK 1**
Crash Scenario Frame Work

Update Crash Scenarios

Define Initial Performance Requirements

**TRACK 2**
Interoperability

IntelliDrive$^{SM}$ System Engineering ◇

◇ Select Applications

Complete Message and Communication Standards

Data Authentication

Final Standards & Protocols

Development Tests

Security & Privacy (Certificate Authority)

**TRACK 3**
Benefits Assessment

Define Performance Measures

Field Trails

Performance Requirements

Develop Objective Tests

Adapt ACAT Methodology

Conduct Objective Tests

Safety Benefits Estimate

◇ Regulation or NCAP Decision

**TRACK 4**
Application Development

Develop & Build Prototype Safety Application Vehicles

**TRACK 5**
Driver Issues

DVI Effectiveness – Multiple Warnings

Driver Workload Issues

Driver Acceptance

**Track 6**
**IntelliDrive$^{SM}$ Policy Issues**

IntelliDrive$^{SM}$ Principles ◇

Retrofit & Aftermarket Req’ts

5.9 Enforcement

Governance (V2V)

Security & Privacy Policy (V2V)

Business Models

**Track 7**
**Commercial Vehicle**

Update Crash Scenarios

Define Initial Performance Reqs and Measures

Develop and Conduct Objective Tests

Driver Workload Issues and Acceptance

Field Tests

(TBD)
CVO Regulation Decision

**Track 8**
**Transit Vehicle**

Update Crash Scenarios

Define Initial Performance Reqs and Measures

Develop and Conduct Objective Tests

Driver Workload Issues and Acceptance

Field Tests

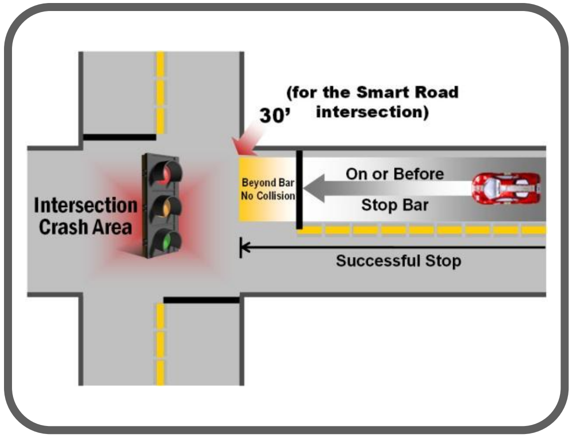
FTA Implementation Decision
(TBD)

# V2I - Cooperative Intersection Collision Avoidance System (CICAS-V)

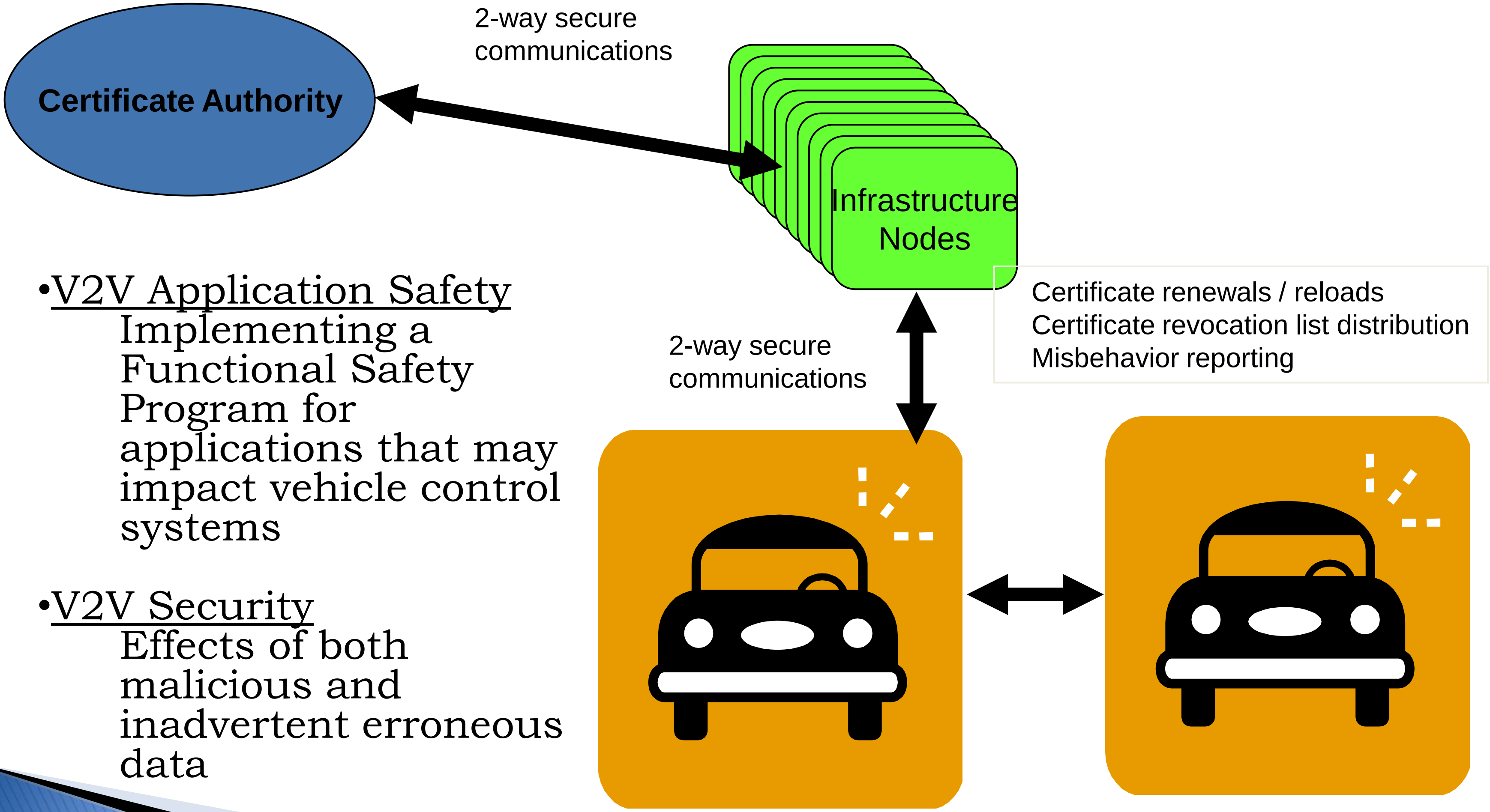
- Stop Sign and Signal Violation Warning System

- Phase 1 – Completed
  - Developed and validated prototype
  - System properly identifies impending violation
  - Delivers timely warning

- Phase 2 – FOT
  - Integrating into IntelliDrive V-I Roadmap



# Interoperability & Security Infrastructure



**Certificate Authority**

2-way secure communications

Infrastructure Nodes

Certificate renewals / reloads
Certificate revocation list distribution
Misbehavior reporting

2-way secure communications

- V2V Application Safety
  - Implementing a Functional Safety Program for applications that may impact vehicle control systems
- V2V Security
  - Effects of both malicious and inadvertent erroneous data

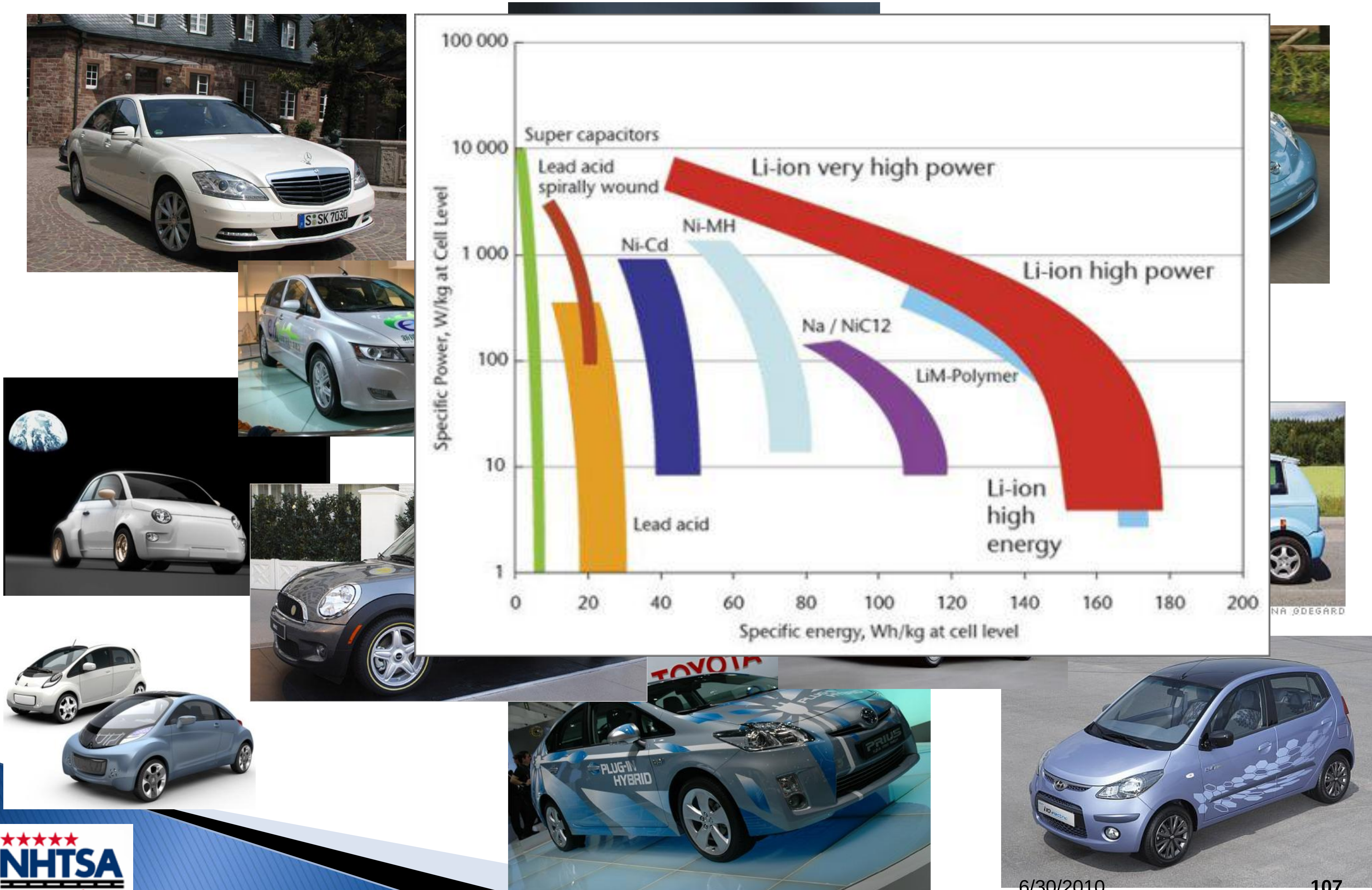
# Vehicle Electronics – Research Activities

- **Vehicle Communications Systems**
  - What can we learn from ETC/UA to prevent similar issues on electronic controls for crash avoidance?

  - Data needs?
  - Research directions?
  - Regulatory requirements?
  - Enforcement methodologies?

# *Battery / Electric Vehicles*

## Lithium-Ion Vehicles: HEV, PHEV, BEV (2009 -2013)

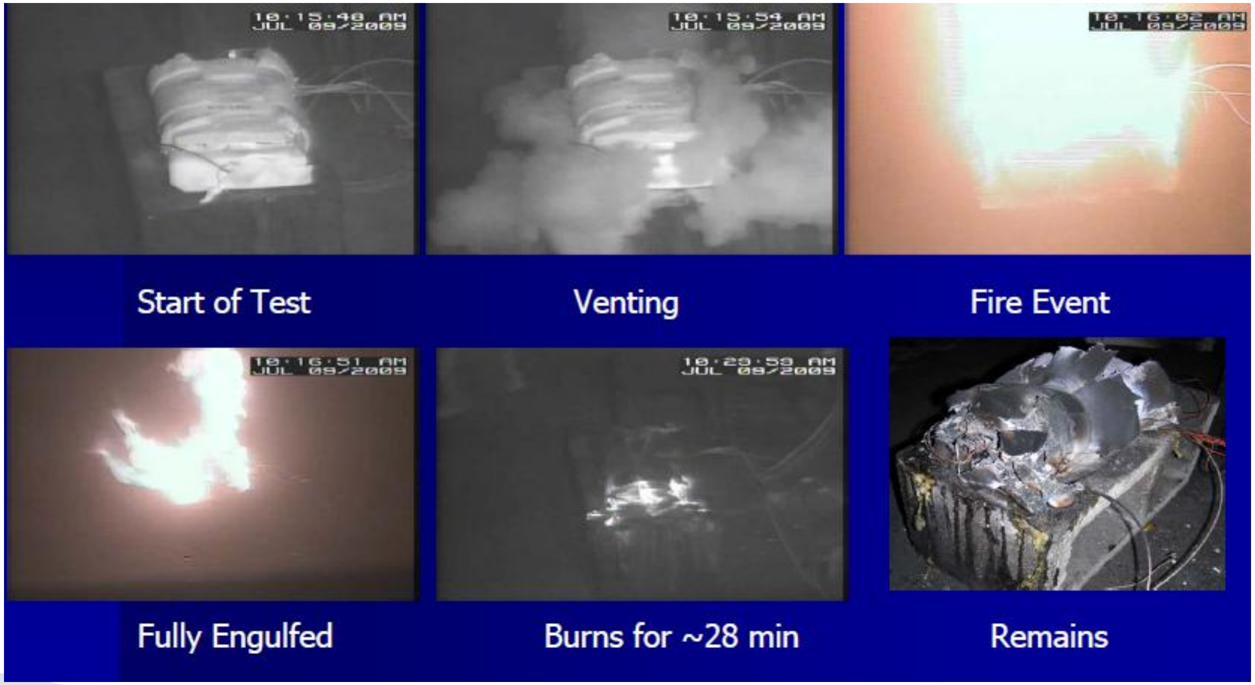


# Vehicle Electronics – Research Activities

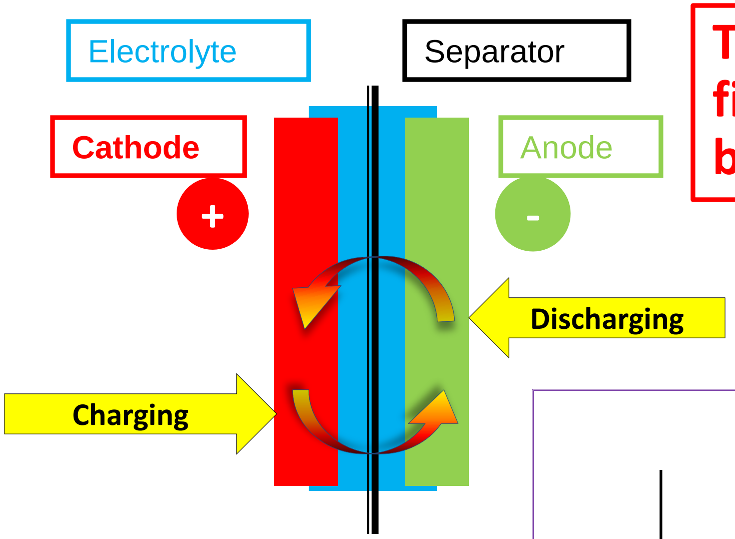
- *Battery / Electric Vehicles*
  - By definition: “throttle by wire”

# Vehicle Electronics – Research Activities

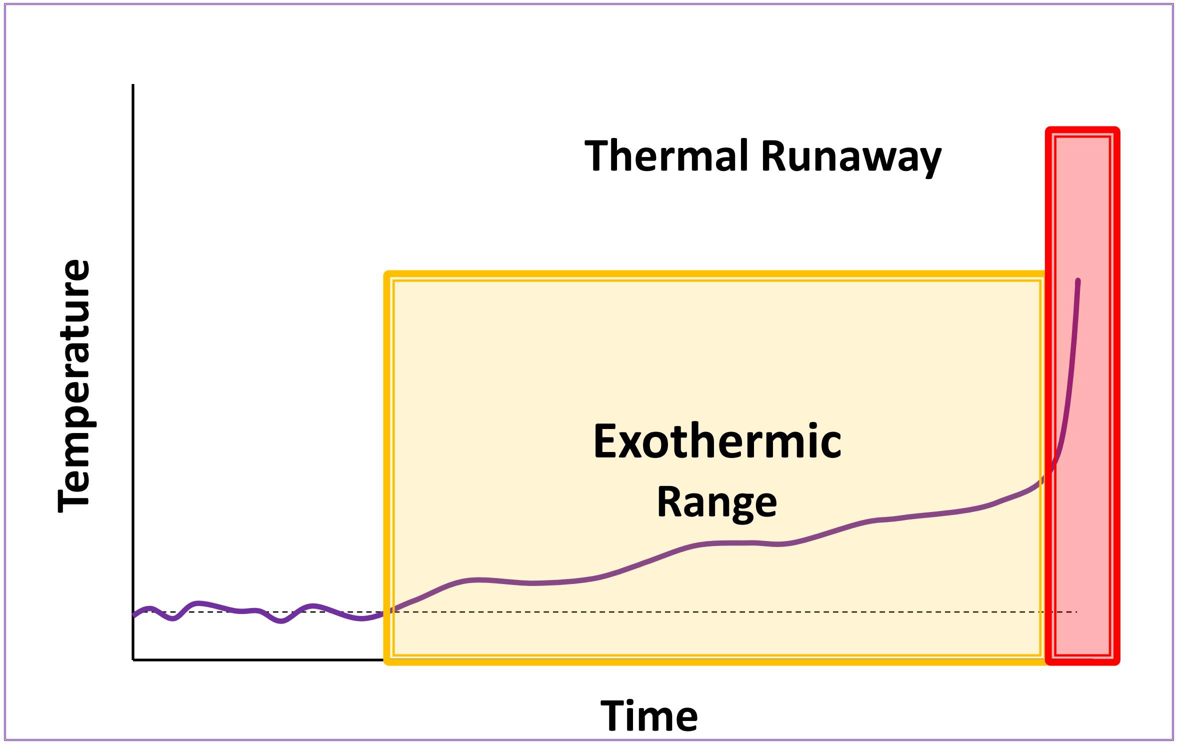
- Lithium Ion safety
  - Cell level – thermal runaway
  - Pack level – overheating & venting
  - Vehicle level – charging/crash/crush



# Lithium-Ion (Li-ion)



**Thermal Runaway includes risk of overheating, fire, and explosion from batteries which have been compromised**



# Vehicle Electronics – Research Activities

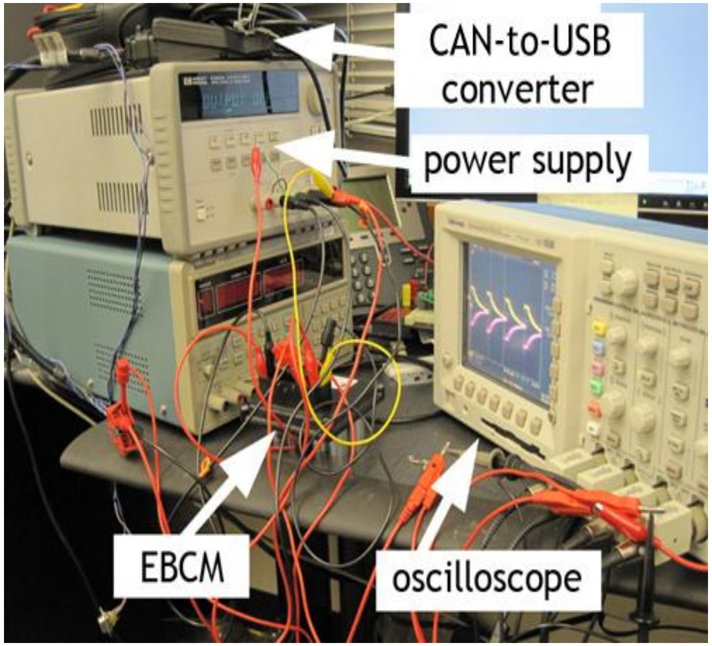
- Battery / Electric Vehicles
  - Controls Safety
    - Monitors cell/pack health, SOC, etc
    - Communicates through CANBus
    - Always on when charging
    - Regulatory Requirements for Battery Controls?
    - Hardware reliability?
    - Software reliability?
    - ……

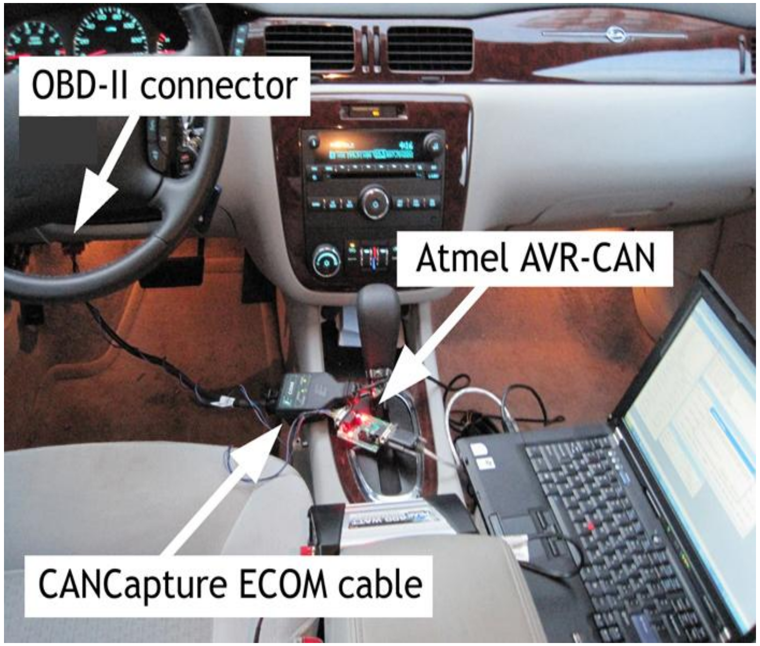
# Vehicle Electronics – Research Activities

- **Vehicle Computer Security**

# Vehicle Electronics – Research Activities

- **Vehicle Computer Security**
  - Paper presented at an IEEE Computer Security & Privacy Conference on May 19th – Kohno, Savage et al



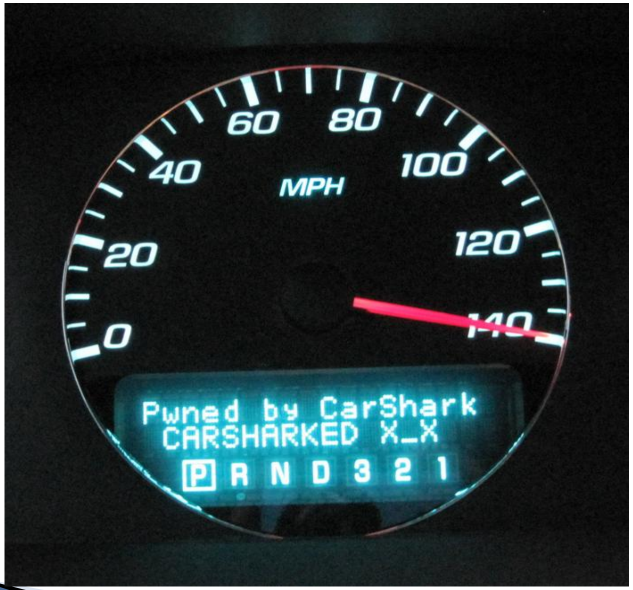


Karl Koscher, Alexei Czeskis, Franziska Roesner, Shwetak Patel, and Tadayoshi Kohno
Department of Computer Science and Engineering
University of Washington

Stephen Checkoway, Damon McCoy, Brian Kantor, Danny Anderson, Hovav Shacham, Stefan Savage
Department of Computer Science and Engineering
University of California San Diego

# Vehicle Electronics – Research Activities

- Able to “adversarially control a wide range of automotive functions and completely ignore driver input—including disabling the brakes, selectively braking individual wheels on demand, stopping the engine, and so on”
- “Malicious Code can self-erase leaving no evidence of its presence”



# Vehicle Electronics – Research Activities

- **Vehicle Security Issues**
  - Similar considerations at FAA, FHWA, FRA, …
  - Increased consequences with Intellidrive connectivity?

  - Data needs?
  - Research directions?
  - Regulatory requirements?
  - Enforcement methodologies?

# Vehicle Electronics – Research Activities

## Vehicle Electronics Expertise

- Aligned with activities on new technologies
- Completely integrated into NHTSA vehicle safety activities
- Must develop and integrate long-term expertise in-house
- But be able to tap outside expertise when needed

# Vehicle Electronics – Research Activities

## Vehicle Electronics - Potential Activities

- Assessing and identifying data needs?
- Electronics Functional Safety approach?
- Driver Override / Fail-Safe approach?
- Hardware requirements?
  - Redundancy approach?
- Software Requirements?
  - Testing & validation approach and tools
  - Software “update” approach

# Vehicle Electronics – Research Activities

## Vehicle Electronics - Potential Activities – continued

- Fault Detection (error codes) requirements?
- Vehicle Security issues & requirements?
- Enforcement of standards?

- New test methods, equipment and facilities?
- Other areas?…..

# Wrap-up and Recommendations

- John Maddox
  Associate Administrator
  Vehicle Safety Research

# Wrap-up and Recommendations

- NHTSA Organization & Process
- UA
- Standards
- Electronic Controls

- Recommendations

# Wrap-up and Recommendations

Recommendations

- Goal: Assure the future safety of electronic throttle control and other electronic vehicle control functions
  - NHTSA data, research, rulemaking, and defects investigation activities & processes
  - Human, expertise, infrastructure, and financial resources required

# Wrap-up and Recommendations

## Recommendations

- Unintended Acceleration – Have we taken the right approach?:
  - Categorizing and understanding reported events
  - Data, and analysis thereof
  - Methodology for assessing potential electronic failures & risks
  - Limitations of testing for rare events
  - New human factors considerations with electronic controls
  - Other considerations?.....

# Wrap-up and Recommendations

## Recommendations

- Standards – need for additional or modified FMVSS?
  - Appropriateness of existing relevant design and testing standards (SAE, ISO, IEEE, etc.);
  - Requirements for electromagnetic compatibility (EMC) and electromagnetic interference (EMI);
  - Need for Software requirements, and nature thereof
  - Need for Redundancy requirements , and nature thereof
  - Are there unique enforcement consideration?
  - Other?……

# Wrap-up and Recommendations

## Recommendations

- Research – What research should we undertake regarding Vehicle Control Electronics reliability?:
  - Data needs and tools
  - Software considerations & testing methods
  - Computer hardware design & testing methods
  - Vehicle systems engineering
  - Driver Override/Fail-safe concepts
  - Best practices from other industries….

# Wrap-up and Recommendations

## Recommendations

- Research – What additional Processes & Methodologies should we consider?
  - Applicability of Functional Safety Approach
  - Human system integration (HSI)/human factors interaction with electronics
  - Data mining and analysis techniques
  - Potential forensic/problem solving methods
  - Other?...

# Wrap-up and Recommendations

## Recommendations

- Organization – What organizational needs & resources are appropriate?
  - Areas of expertise
  - Methods to keep pace with rapidly changing technology
  - Required test equipment and facilities
  - Other?...

# Wrap-up and Recommendations

## Desired Outcomes

- Comprehensive and independent look
- Broad assessment of electronic systems and UA
- Review of possible sources of UA, including mechanical, human, and electronic
- Examination of implications of wide adoption of electronic vehicle controls
- Examination of best practices for assuring safety in other sectors
- Recommendations as described, and others
- Published findings, including information that could be used to advance the state of knowledge

# Wrap-up and Recommendations

Thank You